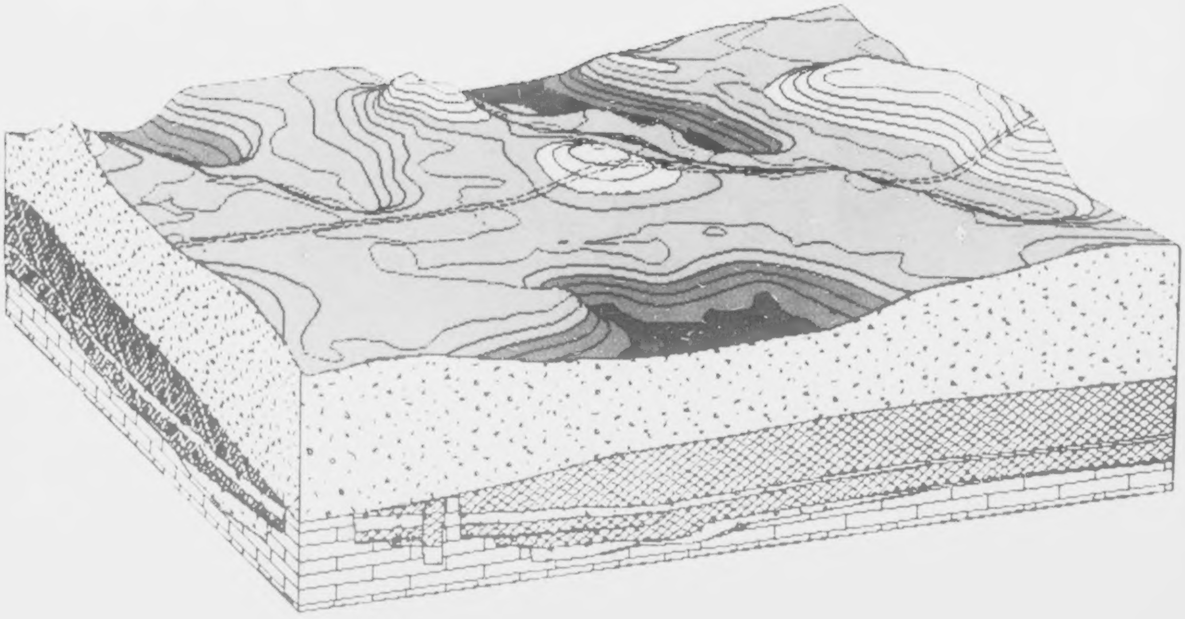
Western Surface Mine Permitting and Reclamation



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Office of Technology Assessment
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California Land Commission

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Lower Colorado River Authority

JOSEPH E. ROSS
Congressional Research Service

MICHEL T. HALBOUTY
Michel T. Halbouty Energy Co.

CARL N. HODGES
University of Arizona

RACHEL McCULLOCH
University of Wisconsin

LEWIS THOMAS
Memorial Sloan-Kettering Cancer Center

Director

JOHN H. GIBBONS

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Western Surface Mine Permitting and Reclamation

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Washington, D.C. 20510

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Foreword

This report responds to a request from the House Committee on Interior and Insular Affairs to assess the ability of current mining and reclamation technologies and methodologies, and of Federal programs and policies, to meet the statutory mandates for environmental protection in reclaiming the surface of Western coal mined lands.

OTA examined the state of development of Western reclamation technologies and methodologies, the adequacy and uses of baseline and monitoring data on mined land reclamation, the reliability of analytical techniques used to predict the impacts of mining and evaluate the success of reclamation practices, and the encouragement given to research and to the development and use of innovative permitting and reclamation technologies. The study also examines the role and effectiveness of lease stipulations and permit conditions as means of imposing technological or methodological requirements for environmental protection and resolving uncertainties in mining and reclamation situations. Technical and policy options for resolving uncertainties about, and for improving the prospects for, successful reclamation on Western Federal lands, including research and development needs, are discussed.

OTA received substantial help from many organizations and individuals in the course of this study. We would like to thank the project's contractors, who prepared the technical background analyses; the project's advisory panel, who provided guidance and extensive critical reviews; and the many additional reviewers who gave their time to ensure the accuracy and objectivity of this report.

John H. Gibbons

JOHN H. GIBBONS
Director

Western Surface Mine Permitting and Reclamation Advisory Panel

James J. Stukel, *Chairman*
Vice Chancellor for Research and Graduate Dean
University of Illinois at Chicago

George Davis
Hydrogeologist
Silver Spring, MD

Robert Flagg*
Manager, Technical and Research Services
Mining and Reclamation Council of America

Tim Gallagher
Assistant Administrator
Montana Department of Natural Resources
and Conservation

L. Thomas Galloway
Attorney
Galloway & Greenberg
Washington, DC

Sheridan Glen
Assistant Vice President
Arch Mineral Corp.

Nick Golder
Rancher
Forsyth, MT

Pat Holderness
Rancher
Hayden, CO

Carolyn Johnson
Environmental Consultant
Denver, CO

Frank Kottlowski
Director
New Mexico Bureau of Mines and
Mineral Resources

George Land
Director, Technology Assessment
AMAX Coal Co.

Cyrus McKell
Vice President, Research
Native Plants, Inc.

Lyle Randen
Environmental Manager
Thunder Basin Coal Co.

Roger Shaffer
Administrator, Land Quality Division
Wyoming Department of Environmental Quality

Patrick Sweeney
Regional Director
Western Organization of Resource Councils

Lauri M. Zell**
Director, Government Affairs
Mining and Reclamation Council of America

Ex officio:

Marlene Berg
Fish and Wildlife Biologist
U.S. Fish and Wildlife Service

Dan Kimball
Environmental Protection Specialist
National Park Service

Al Klein
Administrator, Western Technical Center
Office of Surface Mining

---

*Served as a panelist after August 1985.
**Served as a panelist until August 1985.

NOTE: OTA appreciates and is grateful for the valuable assistance and thoughtful critiques provided by the advisory panel members. The panel does not, however, necessarily approve, disapprove, or endorse this report. OTA assumes full responsibility for the report and the accuracy of its contents.

OTA Project Staff

Lionel S. Johns, *Assistant Director, OTA*
Energy, Materials, and International Security Division

Peter D. Blair, *Energy and Materials Program Manager*

Richard E. Rowberg, *Energy and Materials Program Manager* (until December 1985)

Jenifer Robison, *Project Director*

Martha G. Finnemore, *Baseline and Monitoring Data*
Standards for Reclamation Success
Lease Stipulations

Linda K. Wackwitz, *Senior Technical Analyst*

Administrative Staff

Lillian Chapman Edna Saunders Sharon Scott

Contractors

Jane Bunin

Cedar Creek Associates

James P. Walsh & Associates

Western Resource Development Corp.

Western Water Consultants

Other OTA Contributors

Steven E. Plotkin

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Montana Department of Fish, Wildlife and Parks
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New Mexico Department of Energy and Minerals, Mining and Minerals Division
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Related OTA Reports

- *Technologies To Benefit Agriculture and Wildlife*
  OTA-BP-F-34; May 1985. GPO stock #052-003-00996-0.
- *Protecting the Nation's Groundwater From Contamination*
  OTA-O-233; October 1984. GPO stock #052-003-00966-8.
- *Environmental Protection in the Federal Coal Leasing Program*
  OTA-E-237; May 1984. GPO stock #052-003-00954-4.
- *Wetlands: Their Use and Regulation*
  OTA-O-206; March 1984. GPO stock #052-003-00944-7.
- *Water-Related Technologies for Sustainable Agriculture in U.S. Arid and Semi-arid Lands*
  OTA-F-212; October 1983. GPO stock #052-003-00930-7.
- *U.S. Cropland and Rangeland Productivity*
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- *Development and Production Potential of Federal Coal Leases*
  OTA-M-150; December 1981. NTIS order #PB 82-149378.
- *The Direct Use of Coal*
  OTA-E-86; April 1979. NTIS order #PB 295 797.
- *Management of Fuel and Non-Fuel Minerals on Federal Lands*
  OTA-M-88; April 1979. NTIS order #PB 295 788.

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Chapter 1

Introduction, Findings, and Options

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Chapter 1

Introduction, Findings, and Options

INTRODUCTION

Surface mining is the oldest method of mining coal, from the days of pick and shovel and horse-drawn plows and scrapers, to today's huge operations, each covering thousands of acres and producing as much as 15 million tons per year. With the development of technologies for efficiently mining large amounts of coal by surface methods, however, came concern about the environmental impacts of surface mining. While stream pollution and unstable mountainsides have long been a source of concern in Appalachia, the effects of surface mining in the Western United States did not receive a great deal of attention until the early 1970s. At that time, when the Western industry was beginning to expand greatly, a National Academy of Sciences (NAS) study cast doubt on the ability to develop reclamation technologies and methods suited to the West's vastly different climate, topography, geology, soils, hydrology, and ecology (2).

As far back as the late 1930s, a few States had enacted legislation requiring some form of reclamation of surface mined lands, yet serious abuses continued in many areas. In the early 1970s, the Federal Government's commitment to the development and utilization of coal as a vital part of our national energy future, coupled with the NAS study and the growth of the environmental movement, led to congressional interest in uniform national standards for surface mine reclamation. The 93rd and 94th Congresses passed legislation containing such standards, but both met a Presidential veto (4). In 1977, the Surface Mining Control and Reclamation Act (SMCRA, Public Law 95-87) was approved by Congress and signed by President Carter.

SMCRA established minimum national environmental performance standards for surface mining and reclamation. These standards require, among other things, restoration of disturbed land to original or better conditions and to the approximate original contour, and minimization of disturbances to the existing hydrological balance. The standards are implemented through a permit program, and enforced through inspections and the requirement that mine operators post a performance bond. In its permit application, a coal company must submit a detailed mining and reclamation plan that provides a detailed baseline characterization of all premining aspects of the physical and biological environment, predicts the impacts of mining and reclamation on that environment, demonstrates the ability to meet the performance standards during and after mining, and sets forth a detailed proposal for postmining land use and management.

While SMCRA established a nationwide program for regulating surface coal mining and reclamation, it also recognized that because of the diversity in terrain, climate, biological, chemical, and physical conditions in coal resource areas, the primary governmental responsibility for regulating surface mining should rest with the States. Therefore, provision was made for State regulatory programs consistent with SMCRA, with Federal oversight.

With the advent of SMCRA, the Federal and State regulatory authorities, coal operators, and public interest groups shifted their attention to the ability of mining and reclamation technologies to meet the performance standards, to the reliability of analytical techniques for predicting the impacts of mining and reclamation, and to the adequacy of data to support permitting and leasing decisions.

Moreover, because approximately 70 percent of Western surface mines incorporate Federal coal, the public concern and debate in the 1970s that focused on the Federal coal leasing program became inextricably linked with the concerns about the environmental impacts of surface mining. Thus SMCRA requires that Federal lands be reviewed to determine their acceptability for all or certain types of mining, and provides specific unsuitability criteria that define categories of land that must be protected from, or during mining. These provisions supplemented those of the Federal Coal Leasing Amendments Act (FCLAA, Public Law 94-377) and the Federal Land Policy and Management Act (FLPMA, Public Law 94-579), which require the preparation of a comprehensive land use plan before coal lease sales.

In mid-1983, economic and environmental concerns about the implementation of the Federal coal leasing program led Congress to suspend leasing until completion of reports on the economic aspects of leasing by a newly appointed Commission to Review Fair Market Value for Federal Coal Leasing, and by the Office of Technology Assessment (OTA) on the program's ability to ensure the development of coal leases in a manner compatible with current environmental laws and regulations, including SMCRA and the land use planning provisions of FCLAA and FLPMA (3).

The OTA report, *Environmental Protection in the Federal Coal Leasing Program*, found that the basic framework of the program—the legislative mandates and the use of increasingly stringent analyses from land use planning to mine permitting—is workable and capable of ensuring environmental protection upon development of leased tracts (1). The report concluded, however, that the 1982 changes in the program regulations reduced the effectiveness of the statutory requirements and increased the risk of adverse environmental impacts from the development of some leased tracts.

In particular, OTA found that the increase in the number of tracts to be evaluated for leasing, combined with the rotation and attrition of field personnel, taxed the Bureau of Land Management's (BLM) planning and assessment capability beyond the point where BLM could adequately assess the suitability of the tracts proposed to be offered for lease. OTA also found that, in many cases, BLM's presale data and analyses were inadequate to support a decision on whether recently leased tracts and those proposed for future leases could be developed in an environmentally compatible manner. Consequently, decisions about acceptability of tracts for mining had been deferred beyond lease planning, when they are supposed to be made, to the Secretarial decision or mine permitting stage. Decision deferrals also led to overuse of lease stipulations (conditions placed on a lease) to address gaps in the data and analyses and the resulting uncertainties about impact mitigation requirements. These stipulations would then have to be addressed during permitting. While OTA recognized the importance of ensuring environmental protection during permitting, mining, and reclamation, it was unable to evaluate those aspects of the Federal coal management program within the confines of that earlier assessment.

As a result, the House Committee on Interior and Insular Affairs asked OTA to do a follow-on assessment to assist the committee in its authorization and oversight responsibilities for the implementation of SMCRA. Recognizing "the increasingly important role of mining and reclamation methods in ensuring environmental protection during and after mine development," the Committee asked OTA to assess "the ability of current mining and reclamation technologies and methodologies, and of Federal programs and policies, to meet the statutory mandates." In addition, the Committee requested "guidance about methods for evaluating the success of reclamation practices, including an analysis of the levels and kinds of uncertainty." Due to the Committee's dual oversight responsibilities for Federal lands and for the reclamation program, they restricted the scope of the request to Federal surface mined lands in the Western United States.

In response to this request, OTA designed this assessment to examine six aspects of the implementation of SMCRA in the West:

1. the state of development of technologies and methodologies to reclaim Western surface mined lands;
2. the encouragement given to research and to the development and use of innovative and emerging permitting and reclamation techniques;
3. the reliability of methods, or analytical techniques, for predicting and evaluating the success of reclamation practices, including an analysis of the levels and kinds of uncertainty;

4. the adequacy of baseline and monitoring data on mined land reclamation in the Western United States, and how those data are being used to support 1 through 3, above;
5. the effectiveness of lease stipulations and permit conditions as means of imposing technological or methodological requirements for environmental protection and resolving uncertainties in mining and reclamation situations; and
6. technical and policy options for resolving uncertainties about, and for improving the prospects for, successful reclamation on Western Federal lands, including research and development needs.

It should be noted that this study does not attempt to assess the short- or long-term success of reclamation under SMCRA in the Western United States. While significant reclamation experience has been gained in the 8 years since approval of SMCRA, no Western lands will be eligible for bond release until 1989 at the very earliest. Any such assessment would therefore be premature. Rather, this assessment is limited to analyzing the criteria that may be used to judge the success of reclamation, evaluating the reliability of techniques for predicting the success of reclamation, and defining the remaining uncertainties that need to be resolved before judgments can be made about the long-term success of Western surface mine reclamation.

In response to the Interior Committee's restriction of the scope of the study to Western Federal lands, OTA focused on the four Western leasing regions where there is significant development of Federal coal resources by surface mining methods: the Fort Union, Powder River, Green River-Hams Fork, and San Juan River Coal regions (see fig. 1-1). Although there are substantial amounts of Federal coal in the Uinta-Southwestern Utah Coal Region, all of it is being mined by underground methods. Similarly, while there are a number of surface mines in Oklahoma and Texas that encompass interesting reclamation situations, there is little Federal coal in those areas. Also, mines in Washington and Alaska were excluded because of their limited extent. Surface mine reclamation on Tribal lands was not evaluated due to the ongoing development of a permanent legislative and regulatory program for those lands.

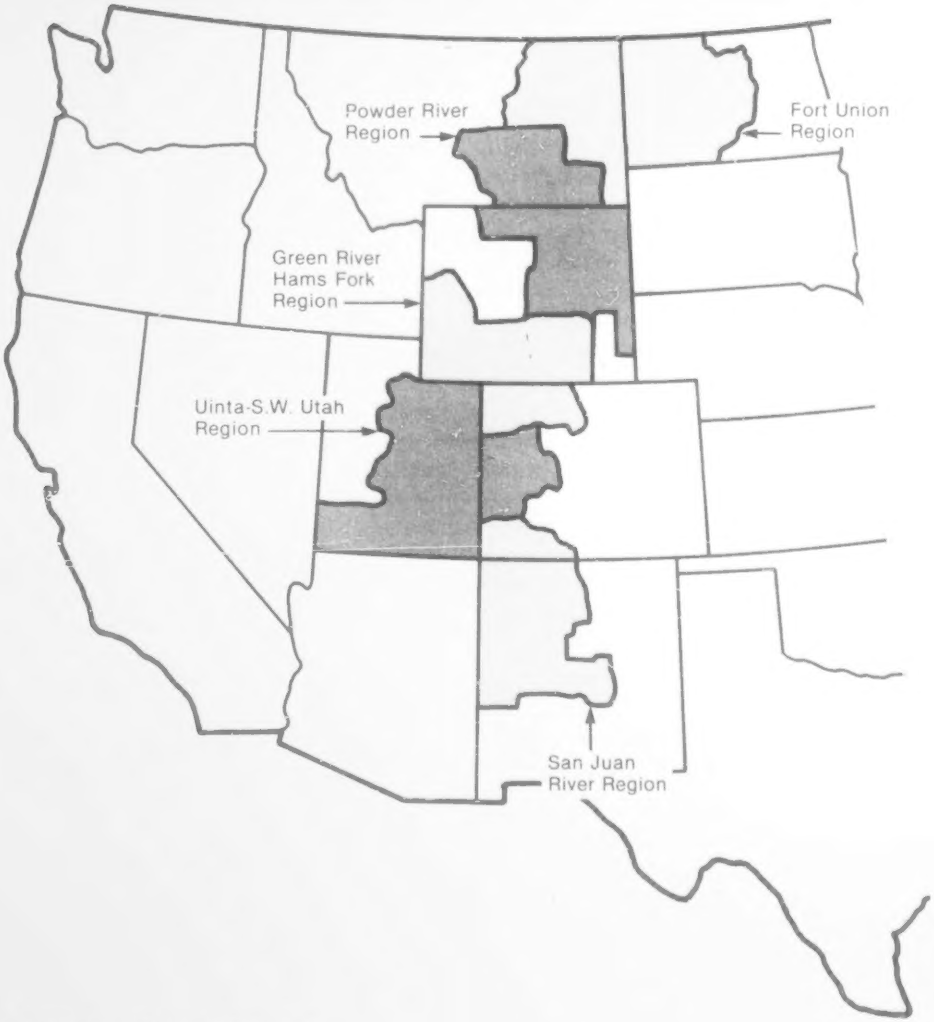
Finally, OTA limited its analysis to those issues related to the physical and biological environment that are specifically addressed by SMCRA: surface and groundwater hydrology, soils and overburden, revegetation, and wildlife. While OTA recognizes that issues related to air quality and to social and economic impacts and surface owner consent may be of equal or even greater concern in some areas, these issues are sufficiently complex that it would not have been possible to address them adequately in this assessment. Although the physical and biological disciplines usually are discussed separately in this report, it is important to keep in mind that surface mine reclamation involves the reconstruction of the surface and subsurface components of a total ecosystem, and all of the aspects of that system are interrelated.

To assist in the formulation of OTA's response to the letter of request, background papers were prepared that evaluate items 1 through 5, above, for the four disciplines (hydrology, soils, vegetation, and wildlife). These reports are appended as volume 2 to this assessment. In addition, the study was assisted by an advisory panel composed of experts on Western surface mine reclamation drawn from the coal industry, environmental organizations, State and local governments, ranchers, academics, and independent research organizations. Interested Federal agencies participated in advisory panel meetings as ex officio members. The panel gave OTA guidance on its study plan and on technical and policy options, and reviewed and commented on drafts of the background papers and this report. While the panel provided advice and comment throughout the course of the assessment, the members do not necessarily approve, disapprove, or endorse the findings of this report, which are the sole responsibility of OTA.

Volume 1 of the report is organized as follows:

- chapter 2 presents OTA's technical findings on the major issues identified in this assessment;
- chapter 3 describes the context for Western surface mine reclamation, including the four

Figure 1-1.—Five Western Coal Regions



SOURCE: Office of Technology Assessment.

coal regions, and the methods used in Western surface mining and reclamation;

- chapter 4 outlines the legislative and regulatory context for Western reclamation, including SMCRA and relevant portions of the leasing program, and identifies the Federal and State agencies that implement them;
- chapter 5 discusses the data requirements and collection methods for surface mine planning and permitting and assesses the availability and adequacy of baseline and monitoring data;
- chapter 6 evaluates the analytical techniques used to predict the impacts of mining and to design reclamation strategies;
- chapter 7 reviews the criteria and methods that have been developed to evaluate the success of reclamation;
- chapter 8 examines a variety of specific technical issues related to the long-term success of Western surface mine reclamation; and
- chapter 9 discusses ongoing research and innovation in reclamation, outlines research needs, and identifies the constraints on re-

search and options for removing those constraints.

The following section briefly reviews OTA's findings and lists technical and policy options that Congress might consider in its oversight of SMCRA and the regulatory programs. The options, the congressional and Federal agency actions they may entail, and their potential costs and benefits are summarized in table 1-1 and discussed in greater detail in chapters 2 through 9. Some of these options would be relatively easy to implement, while others would be more difficult or controversial. Potential problems with their implementation are noted in the discussion in the main body of the report.

FINDINGS AND POLICY OPTIONS

Surface coal mining in the Western United States is a relatively new activity compared to Eastern mining, and its operational and regulatory characteristics are different from those in the East. Most Western mines have been developed since the early 1970s, and, unlike Eastern mines, many operate on public lands with Federal coal. The technical uncertainties related to the expansion of surface coal mining in the West, arising from the West's vastly different—and highly variable—climate, topography, geology, soils, hydrology, and ecology, were studied prior to enactment of SMCRA, and the legislative requirements for mining and reclamation permits, performance standards, and bonds recognized certain risks associated with those uncertainties.

Knowledge gained about Western mining and reclamation situations in the intervening years has resolved many of the technical issues, and **the prognosis for the long-term success of reclamation in the West has brightened considerably. Some technical uncertainties still exist about several aspects of reclamation, particularly about methods for delineating overburden material that may be detrimental to revegetation and water quality, and about the success of hydrologic restoration. These uncertainties were recognized at the time SMCRA was debated and approved. The coal industry and the regulatory authorities have learned a lot more about these problems in the intervening years, and, while much work remains to be done, in OTA's view the risks these uncertainties may pose to the long-term success of Western reclamation have been reduced significantly.** Further resolution of these uncertainties and other outstanding technical issues would increase the probability of success as well as the quality of Western reclamation, make permitting and designing Western surface mines easier, and reduce the costs of regulation and reclamation.

Resolving Uncertainties

The remaining uncertainties about the reclamation of surface mined lands in the West arise primarily from inadequate or unverified analytical techniques for accurately predicting the impacts of mining and planning reclamation. In particular, the geology of some Western coal regions is so variable and/or complex that the occurrence of overburden material detrimental to postmining water quality or revegetation is very difficult to predict. Similarly, the slow recharge rate of some Western aquifers makes it difficult to judge the effectiveness of current plans for restoration of the hydrologic balance until years after final bond release. Accurate quantitative methods for predicting and evaluating impacts to wildlife also are lacking.

Current regulatory requirements may not provide sufficient latitude to industry in choosing predictive and other analytical techniques that may compensate for these uncertainties. Rather, reclamation designs based on worst-case impact assessments must be used, which increases the cost of mining and reclamation.

Options for resolving these and other technical uncertainties include:

1. Increase and improve the analysis of monitoring data from ongoing mining and reclamation in order to improve the accuracy of

Table 1-1.—Summary of Policy Options

Option	Possible ranges of congressional action	Federal agency actions	Potential costs and benefits
Resolving uncertainties:			
1. Analyze monitoring data to improve analytical techniques	None for voluntary industry analysis Directive in appropriations for OSM analysis or revision of regulations to require industry or RA analysis Amendment of SMCRA needed to mandate RA analysis plus oversight and budget authorization	Formal rulemaking to specify types of analyses required	High for industry, oversight for RAs High for RAs or OSM, rulemaking and oversight for OSM Rulemaking and oversight for OSM high for RAs or industry
2. Define goals of analysis to focus on resolving uncertainty	Directive in appropriations Oversight and authorization Hearings	Rulemaking to define goals	Rulemaking and oversight; improved cost-efficiency
3. Research and development on analytical techniques and physical and biological systems	Directive in appropriations Oversight and authorization Hearings	Budget reallocation Continuing supervision or implementation	Government or industry allocation of research funds Agency oversight
4. Provide regulatory latitude on selection of analytical techniques	Directive in appropriations Oversight and authorization	Analysis of available techniques Formal or informal rulemaking Oversight of State programs	Supervision of analysis Rulemaking/oversight for OSM More flexibility and lower costs for industry, but also potentially greater risk of reclamation problems
Data adequacy and management:			
5. Standardize data collection methodologies and data formats in regulations	Directive in appropriations Oversight and authorization Amend SMCRA to mandate standardization	Analysis of available methodologies Formal or informal rulemaking Oversight of State programs	Supervision of analysis Rulemaking/oversight for OSM Less flexibility but also possibly lower costs for industry
6. Develop a scoping process for baseline and monitoring data collection	Directive in appropriations Oversight and authorization Amend SMCRA to mandate process Hearings	Formal or informal rulemaking Oversight of State programs	Rulemaking/oversight for OSM Lower costs and increased efficiency for industry and agency data collection and analysis
7. Develop integrated databases from permitting and other information	Directive in appropriations Oversight and authorization Mandate development in legislation Hearings	Budget reallocation Supervision or implementation of database development Continued supervision or maintenance of databases	Initial cost very high Continued commitment to database management Long-term reduction in data collection costs for all affected Federal and State agencies and permit applicants
8. Continue to develop multidisciplinary approach to data collection/analysis	Oversight and authorization	Commitment to the continual integration of all available information to continually refine understanding of reclamation	Potential long-term savings for agencies and industry
9. Develop valid methods for generating and interpreting overburden chemical data	Directive in appropriations Oversight and authorization	Formal or informal rulemaking Coordination of industry efforts Oversight of State programs	Rulemaking/oversight for OSM
Evaluating reclamation success:			
10. Evaluate phase II and III bond release criteria	Directive in appropriations Oversight and authorization Hearings Amend SMCRA to mandate criteria for specific disciplines	Analysis of existing and possible criteria Formal rulemaking Oversight of State programs	Supervision of analysis Rulemaking/oversight for OSM Greater certainty for industry and agencies
11. Establish procedure for periodic reexamination of bond release criteria	Directive in appropriations Oversight and authorization Hearings Amend SMCRA to mandate procedure for specific disciplines	Analysis of possible procedures Formal rulemaking Implementation in Federal program Oversight of State programs	Supervision of analysis Continued implementation Rulemaking/oversight

Table 1-1.—Summary of Policy Options—Continued

Option	Possible ranges of congressional action	Federal agency actions	Potential costs and benefits
Post-bond release liability:			
12. Research the identification and handling of deleterious overburden	Directive in appropriations Oversight and authorization	Budget reallocation Supervision or conduct of research Eventual incorporation of research results in regulatory programs	Initial cost high but potential long-term benefits great for agencies and/or industry
13. Examine need for congressional policy on post-bond release reclamation failure	Hearings	None	Greater certainty for all parties
Technical Issues:			
14. Develop valid test for ABP in Western overburden and incorporate in regulatory programs	Directive in appropriations Oversight	Supervision of research Formal or informal rulemaking	Research cost moderate Potential long-term benefits great
15. Collect data on sedimentation and control methods	Hearings Directive in appropriates Oversight and authorization	Supervise data collection Formal rulemaking Oversight of State programs	Data collection costs high Potential long-term benefits great
16. Promote optimization of the soil resource	Hearings Oversight and authorization	Formal or informal rulemaking Oversight of State programs	Rulemaking/oversight Lower reclamation costs Improved prospects for revegetation success
17. Reexamine woody plant density standards	Hearings Directive in appropriations Oversight and authorization	Formal or informal rulemaking Oversight of State programs	Rulemaking/oversight Lower reclamation costs Improved prospects for revegetation success and landscape diversity Fewer postmining land use conflicts
18. Ensure OSM and BLM coordination on postmining land use characterization and implementation	Oversight and authorization	Commitment to coordination on part of both agencies	Initial costs slightly higher but potential long-term benefits great
19. Enforce requirements for quantitative characterization of pre- and postmining land uses	Oversight	Increase BLM scrutiny of permit applications Stricter OSM enforcement of SMCRA Oversight of State programs	Slightly higher permit review costs Greater certainty in reclamation requirements
20. Research the costs and benefits of landscape diversity	Directive in appropriations Oversight and authorization	Supervise research Analysis of results Formal or informal rulemaking Adoption of integrated approach to reclamation planning	Potential for long-term benefits in ecosystem function and viability
Innovation and research:			
21. Clarify regulatory policy on experimental practices vs. alternate reclamation techniques	Directive in appropriations Oversight and authorization Hearings	Formal or informal rulemaking Change in OSM approach to both Oversight of State programs	Rulemaking/oversight Lower reclamation costs Greater regulatory efficiency
22. Establish strict schedules for approval of experimental practices	Directive in appropriations Oversight and authorization Amend SMCRA to mandate schedules	Formal rulemaking	Lower review costs Greater efficiency in permitting Increased use of experimental practice option Less strict review
23. Establish local advisory committees to review applications for alternate techniques	Directive in appropriations Oversight and authorization Hearings Legislation mandating committees	Implementation of legislation or rulemaking Appointment of committees Oversight of committees	Initial adjustment likely to be difficult Major benefits for public confidence in regulation Strict definition of mandate and review schedules could ease adjustment process

Table 1-1.—Summary of Policy Options—Continued

Option	Possible ranges of congressional action	Federal agency actions	Potential costs and benefits
24. Increase appropriations for and/or develop new avenues for funding research	Reallocation of revenue Oversight and authorization Hearings	Improve management of research revenues	Lower administrative costs Higher research costs
25. Establish cooperative Western reclamation research organization	Oversight and authorization	Assist in determination of resarch priorities	Voluntary industry funding
26. Establish mechanism for disseminating research results	Directive in appropriations Oversight and authorization Legislation mandating establishment	Manage publication and distribution Oversight of State publication and distribution	Potentially high, depending on subscription price
Regulatory authority personnel:			
27. Provide greater career incentives for technical personnel	Directive in appropriations Hearings	Changes in management and personnel policies Oversight of State programs	Greater regulatory efficiency
28. Reduce frequency of personnel transfers and rotations	Directive in appropriations	Changes in management and personnel policies	Greater regulatory efficiency
29. Ensure adequacy of State program funding for technical personnel	Oversight	Oversight of State programs	Greater regulatory efficiency Potentially higher State program costs
30. Evaluate Federal and State roles in permit review	Directive in appropriations Oversight and authorization Hearings	Changes in management and personnel policies	Greater regulatory efficiency Lower permit review costs
31. Establish computerized databases on leasing and permitting decisions	Directive in appropriations Oversight and authorization	Develop database format Set up and maintain database	Relatively low initial and maintenance costs
Lease Stipulations:			
32. Evaluate the need for and role of lease stipulations	Directive in appropriations Oversight and authorization Hearings	BLM/OSM coordination on analysis	Supervision of analysis Increased efficiency in leasing and permit review
33. Require BLM to establish uniform permit review procedure and require coordination in development and documentation of compliance review for lease stipulations	Directive in appropriations Oversight and authorization	BLM (or USFS) coordination with OSM in developing lease stipulations Establish BLM procedure for documenting review of compliance with stipulations	Relatively low initial and maintenance costs Increased efficiency in leasing and permit review

"RA" means Regulatory Authority.

SOURCE: Office of Technology Assessment

predictive and design techniques (see also the separate discussion of data, below).

2. Clearly define, in the Federal and State regulatory programs, the goals of pre- and postmining analyses of the potential and actual impacts of mining and reclamation in order to ensure that such analyses focus on remaining areas of uncertainty and are integrated with reclamation goals in order to increase the efficiency of reclamation planning and permitting (also see option 6).
3. Devote additional Federal, State, and industry research and development resources to improving the quantitative techniques for predicting the impacts of mining and designing successful reclamation, and to improving our understanding of the physical and biological systems to be reestablished (see separate discussion of research, below, for more specific means of achieving this).
4. Examine the Federal and State regulatory programs to determine whether they provide sufficient latitude in the selection of analytical techniques for predicting the impacts of mining and designing reclamation appropriate to site-specific reclamation conditions in the Western United States, and incorporate such latitude where it currently is insufficient.

Data Adequacy and Management

Although the quantity and quality of data on Western reclamation have increased dramatically since the passage of SMCRA, data-related problems still limit the accuracy and efficiency of reclamation planning and evaluation. First, **the large quantity of data being collected has raised serious data management problems for both mine operators and regulatory authorities.** In some disciplines, especially hydrology, the quantity of monitoring data is so large that regulatory authority personnel and resources rarely are available to review it. The lack of a standardized or computer-accessible format for baseline and monitoring data also makes it difficult and/or very expensive for regulatory authorities to review the data, complicates the integration of data into regional analyses (particularly cumulative hydrologic impact assessments), and constrains the efficient use of available data by other groups.

Moreover, **despite recent improvements, collection of reliable data still is difficult for some parameters, either because standardized data collection methodologies are lacking, or laboratory techniques for generating data need to be refined, or there are natural obstacles to collecting the data.** The lack of reliable methods for interpreting the results of laboratory techniques that generate chemical data about overburden pose potential risks to postmining water quality and revegetation. Repairs are very difficult and costly if unanticipated overburden problems are found during reclamation monitoring and evaluation. Standardized methods for collecting data on flow and water quality in ephemeral streams and on wildlife habitat quality also are lacking, increasing the difficulty of industry planning and regulatory review of reclamation in these areas. The lack of monitoring data on spoils recharge from pump tests contributes to the uncertainty about the long-term success of hydrologic restoration.

Options for improving data collection and management include:

5. Incorporate guidelines for standardized data collection methodologies and formats for data presentation in the regulatory programs in order to increase the efficiency and accuracy of industry planning for reclamation, facilitate regulatory authority review of that planning, and facilitate the use of baseline and monitoring data in regional analyses.
6. Develop a scoping process similar to that used for environmental impact statements to optimize the quantity and format of baseline and monitoring data in order to eliminate unnecessary data collection and to facilitate data review and analysis by operators and regulatory authorities.
7. Develop integrated databases from permit applications and other sources to facilitate regional impact assessments and to ensure that baseline and monitoring data are accessible to other organizations to which such data could be useful.

8. Continue to develop a multidisciplinary approach to data collection and analysis that integrates actual on-the-ground conditions with reclamation planning and evaluation for all of the disciplines addressed.
9. Encourage coordinated research efforts to develop valid methods for generating and interpreting overburden chemical data.

Evaluating Reclamation Success

Criteria for bond release on reclaimed areas have not yet been formulated beyond the first phase of release (backfilling the pit) in the five Western States studied. Furthermore, most existing evaluation methods and standards have serious limitations, especially those for evaluating postmining hydrology and revegetation—the two areas emphasized in the SMCRA performance and design standards. Most past experience in judging the success of reclamation has concentrated on revegetation success, yet no method has been developed that adequately accounts for both temporal variations in environmental conditions and the spatial diversity in vegetation that occurs over large areas. The tens to thousands of years that may be required to resaturate spoil aquifers, and the infrequent peak flow events in Western drainages mean that evaluations of reclamation success in these areas must be made with incomplete knowledge and predictive techniques. Despite these limitations, "successful" revegetation and hydrologic restoration are used as the primary indicators of success for the other disciplines—soils, overburden, and wildlife.

Establishing criteria for the second and third phases of bond release on a statewide or regional basis may be difficult because of the wide variability among Western mining and reclamation situations. In addition, knowledge about reclamation in the West is increasing rapidly, and bond release criteria should be reviewed periodically or be sufficiently flexible to incorporate research and monitoring results. Yet, if regulators do develop Phase II and III bond release criteria, they may find their flexibility to establish detailed criteria limited by previously approved reclamation plans that establish de facto criteria on a case-by-case basis. A decision about the appropriate type and level of criteria best suited to Western mining conditions requires further study.

Options for increasing the certainty in the success evaluation process include:

10. Evaluate the relative expediency of statewide versus areal versus mine-specific criteria for all disciplines for the second and third phases of bond release, and establish such criteria based on the results of that evaluation.
11. Establish a procedure for periodic reexamination of bond release criteria that incorporates advances in reclamation technology based on research results and monitoring data but considers the effects of any change in criteria on existing permits.

Post-Bond Release Liability

Evaluation of the first phase of bond release (backfilling) may be inadequate in some areas to ensure that deleterious spoil material has not inadvertently been placed in the water table or in the root zone. While vegetation monitoring ultimately could reveal the presence of deleterious spoil in the root zone, subsequent reconstruction of the affected areas would be very expensive. Furthermore, the long-term results of placement of such spoils in groundwater may not become evident until the spoil has resaturated. This may not occur for decades or even centuries—long after final bond release—creating both technological and legal uncertainties about how such water quality problems would be corrected. While OTA was unable to quantify the potential for or scope of impacts from this problem, we believe it to be sufficiently serious that it should be given high priority in reclamation research and planning. Until judicial decisions on the issue become available, it is unclear who will be liable for reclamation problems that arise after final bond release has been obtained.

Options for clarifying post-bond release liability include:

12. Support and expand research on ways to identify and handle deleterious overburden

prior to and during mining in order to minimize the possibility of such material becoming an environmental hazard by being placed in the water table or root zone.

13. Examine the need for a congressional policy for accommodating post-bond release reclamation failures in lieu of judicial decisions on a case-by-case basis.

Technical Issues

Technical issues highlighted in this assessment encompass the technologies, data, and analytical methods related to the acid-base potential of Western overburden, the impacts of sediment control methods, the effects of soil handling on revegetation, the ability to meet uniform high woody plant revegetation standards, the characterization and implementation of postmining land uses, and the potential value of restoring landscape diversity.

Acid Potential in Western Mine Spoils

There are conditions under which acid formation will occur in Western postmining spoils, primarily in portions of the Powder River Basin and in New Mexico. If acid-forming materials are placed in the postmining root zone, they can be detrimental to revegetation. **But, available techniques for estimating the acid-base potential of overburden, and thus the possible magnitude of its adverse impacts, have produced unreliable results in the West. As a result, some operators have failed to identify materials that need special handling, while others have been required to special handle some materials unnecessarily.** Research currently being funded by Western mine operators is making progress in solving this problem.

Sediment Control

Sedimentation ponds—the current design standard for controlling the sedimentation in streams that is caused by soil and overburden disturbance in mining and reclamation—are expensive to build and maintain and increase the amount of land that must be disturbed in mining. Their storage and release of water also can have adverse impacts on downstream surface water quantity and quality. **Alternate means of maintaining sediment production at or below the level produced from undisturbed Western terrain are considered proven technology in agriculture, highway construction, and other land-disturbing activities.** To support a proposal that the design standards for sediment control be revised, operators need to demonstrate that alternate means of control are as effective as sedimentation ponds in Western surface mining. Such a demonstration will require empirical data on sediment yields and on natural sediment concentrations in streams, plus monitoring data from areas where alternate controls are in use.

Soil Handling and Revegetation

In the Western coal regions, where natural soils in many areas are thin and marginally productive, optimization of the soil resource is essential to the success of revegetation. **Cumulative Western mining experience suggests that hauling topsoil directly to a reclamation site, rather than stockpiling it, preserves the biologically active component of the soil and thus improves the establishment of planted and volunteer species, and can produce superior lifeform and species diversity within a relatively short time.** Research in deep soils and the limited monitoring data available suggest that combining direct hauling with two lifts (separate handling of surface and subsoils) may produce the best results in reestablishing rangeland diversity. However, **State programs that require salvage of *all* suitable soil materials and redressing in uniform thickness may not promote optimization of the soil resource in all mining and reclamation situations, and may add unnecessarily to reclamation costs.**

Revegetation of Woody Plants

Because woody plants—trees, shrubs, and subshrubs—are ecologically important in the West, the revegetation performance and success standards are tied in part to the reestablishment of native woody plant species of the same type and density that existed on the site before mining. This raises several concerns, especially in areas where the premining density may be artificially high due to overgrazing or other factors (primarily Wyoming, Colorado, and New Mexico). First, **even with the most advanced shrub establishment technology, there is little field evidence that high densities can be reestablished over an entire reclamation site during the 10-year liability period,** with sagebrush being among the most difficult to reestablish.

Second, **while groupings of shrubs in moderate to high densities improve habitat quality for a variety of animal species, high uniform woody plant densities detract from the quality of the land for livestock grazing.** As a result, ranchers have undertaken large-scale programs to thin or kill sagebrush and other woody species, frequently under the auspices of BLM's rangeland management program. **Lower woody plant densities, if accomplished as groupings based on premining habitat mapping, could mitigate this conflict between revegetation requirements and postmining range management, yet still provide wildlife habitat as valuable as high uniform premining densities.**

Postmining Land Use

The conflict between shrub density standards and range management, as well as other reclamation-land use conflicts, can in part be traced to lack of specificity in designation of the postmining land use during permitting. **Despite legislative and regulatory requirements for the quantitative characterization of the pre- and postmining land capability and productivity, the land use characterizations in most permit applications reviewed for this assessment are at best perfunctory.** A number of the applications contained land use discussions with little more information than the statement "The premining land use is grazing and the postmining land use will be grazing." In some cases, this lack of specificity can be attributed to inadequate baseline data in the permit application; in others it is the fault of the Federal surface management agency, which is required to determine, or at least consent to, the postmining land use.

Landscape Diversity

Requiring full restoration of "landscape diversity"—the mosaic nature of Western landscapes resulting from localized differences in the physical environment, plant communities, wildlife populations, and land uses—would go beyond the premises of SMCRA and might be too inflexible for adaptation to changing technology and to climatic and other uncontrollable variables. Yet some attention to the various components of landscape diversity is needed to ensure long-term ecosystem function. Surface features typically eliminated in mining include rimrock and escarpments, ridges, badland topography, and "microsites" (small premining surface features important to hydrology or wildlife habitat).

Some landforms (e.g., hogback ridges and badlands) are impossible to reestablish, and others may be too costly or difficult for all but the most elaborate reclamation plans. Many others can, however, be mimicked in the postmining topography (e.g., a section of unreduced highwall creates an artificial cliff that simulates rimrock). Regulatory authorities have required the restoration of landscape diversity at specific mines on a case-by-case basis, primarily for vegetative communities such as ponderosa pine woodlands, woody draws, and wetlands. On the other hand, regulatory requirements for uniform topsoil depth and full highwall reduction tend to homogenize postmining site conditions, and may discourage diversity in some mining and reclamation situations.

Attention to landscape diversity would require a reclamation plan with integrated analyses of the relations among the postmining topography, surface and groundwater hydrology, revegetation communities, land use, and the geomorphology of the contiguous areas. **Long-term research efforts are needed to demonstrate whether the potential benefits of such an approach for ecosystem function and viability would outweigh the costs.**

Options for resolving these technical issues include:

14. Continue industry and regulatory authority efforts to develop a valid, reliable test for acid-base potential in Western mine spoils, and then incorporate the results in

State guidelines for analytical techniques and overburden suitability.

15. Increase data collection efforts on the relative effectiveness of sediment control ponds versus alternate controls to determine whether the design standard for sediment control could be implemented more flexibly on a case-by-case basis.
16. Implement the regulations on soil salvage and redressing thickness more flexibly to promote optimization of the soil resource and improve revegetation success.
17. Reexamine woody plant density standards to determine whether lower overall densities accomplished in high-density groupings would resolve the postmining conflicts between wildlife habitat and range management.
18. Ensure coordination between OSM's reclamation programs and BLM's range management programs in the specification and management of postmining land uses.
19. Enforce the requirements for the detailed quantitative characterization of pre- and postmining land uses, productivity, and capabilities more strictly to provide greater guidance to operators in reclamation planning and to land use management agencies in permit application and reclamation review (see also option 33).
20. Institute a research program to examine the costs and benefits of a landscape diversity approach to reclamation.

Innovation and Research

Cutbacks in funding have significantly reduced reclamation research. Also, there are few vehicles for dissemination of research results, leading to delays in the adoption and regulatory approval of improved reclamation techniques. In addition, OSM's inflexible application of some design and performance standards for reclamation, and strict interpretation of the experimental practice provision of SMCRA can stifle innovation in reclamation. Although greater regulatory flexibility might increase the probability of challenges to permitting decisions, it also could increase the long-term quality and reduce the costs of reclamation, particularly in the areas of replacement of uniform topsoil depth, technological design standards for sediment control, and high uniform shrub density standards.

Options for increasing innovation and research include:

21. Develop a Federal regulatory policy that distinguishes between formal experimental practices and site-specific variances or alternative reclamation techniques in Western mining and reclamation situations, and provide greater regulatory flexibility in approving the latter when the operator demonstrates they will be at least as effective in meeting reclamation standards as traditional methods or technologies.
22. Establish strict schedules for regulatory authority approval of experimental practices to ensure that they can be implemented effectively within the context of the mining and reclamation schedule.
23. Establish local advisory committees to review permit applications that propose site-specific variances or alternative reclamation techniques to ensure that local concerns about their potential impacts are considered fully and to facilitate their approval by the regulatory authority.
24. Increase appropriations for reclamation research and/or develop new avenues for funding research within existing Federal (and State) revenues (e.g., from existing permit fees, royalties and bonus payments on coal leases, the abandoned mine reclamation fund, severance taxes).
25. Establish a cooperative Western reclamation research organization with industry and government funding to encourage research on resolving uncertainties, and promote innovation and information exchange.
26. Establish a mechanism for disseminating the results of research projects and analyses of monitoring data, such as regular publication of a newsletter or journal by the OSM Western Technical Center (or the State regulatory authorities).

Regulatory Authority Personnel

Personnel cutbacks, rotations, and turnover in Federal and State regulatory and land use management agencies impair retention of an institutional memory about lease tracts and reclamation plans, contribute to regulatory inconsistency and inefficiency, increase the cost of permit and reclamation review, and impair OSM's ability to provide technical assistance to State regulatory authorities. Two continuing problems are: 1) the wide disparity among salaries for State employees (at the low end of the scale), Federal agencies, and industry (at the high end); and 2) the tendency in government agencies to promote competent technical personnel to management positions. Both of these encourage technical specialists to begin their careers in the State regulatory authorities but to leave for government management or industry positions as soon as they have gained some experience.

Options for preserving technical expertise in Federal (and State) agencies and improving the quality and consistency of leasing and permitting decisions include:

27. Provide greater career incentives for experienced technical personnel to remain in Federal (and State) government service, and to remain in technical positions, through such means as expanding the grade levels available to technical and field personnel, or placing more emphasis on technical expertise in career advancement.
28. Reduce the frequency of personnel transfers and rotations, and of reorganizations in Federal agencies.
29. Pay greater attention, in Federal oversight of State programs, to the adequacy of State funding for ensuring sufficient technical expertise, and the adequacy of Federal technical assistance to the States (e.g., through personnel details).
30. Reevaluate the respective roles of State and Federal regulatory authorities in technical review of permit applications, in order to eliminate duplication and improve the efficiency of permit review, and to promote State primacy.
31. Establish computerized databases on Federal coal leasing decisions and on mining and reclamation permit decisions to aid new personnel in becoming familiar with past actions and their rationale.

The Fate of Lease Stipulations During Permitting

Determining the fate of lease stipulations during permitting is difficult because **BLM does not have an established uniform permit review process, and neither BLM nor OSM makes a written finding that lease stipulations have been complied with in approving a reclamation plan and permit. The absence of a formal process and any documentation of its completion is compounded by the rapid turnover and rotation of BLM personnel in district and resource area offices, leading to a lack of institutional memory on the treatment of lease stipulations during permit review.** Based on OTA interviews with BLM personnel, it is clear that the primary emphasis in their permit review process is on full and efficient recovery of the Federal coal resources, and environmental review is secondary. Further, the environmental review focuses on compatibility with the approved postmining land use and with the resource area land use management plan, not on compliance with lease stipulations.

In examining the BLM lease stipulations themselves, OTA found that they are too vague and general to provide meaningful guidance to lessees or permitting agencies on long-term Federal land use objectives or to fulfill their intended purpose of alerting these groups to potential reclaimability problems on Federal lease tracts. The vagueness of lease stipulations also contributes to the potential for increased environmental risk in the leasing process due to inadequate preleasing data and analysis, as reported in OTA's 1984 assessment of *Environmental Protection in the Federal Coal Leasing Program*, especially in light of the fact that there is little or no probability that a negative finding of reclaimability will be made on a tract once it has been leased.

Options for clarifying the need for and improving the effectiveness of lease stipulations are:

32. Require the Bureau of Land Management to evaluate the need for and role of lease stipulations in light of the detailed analysis during permitting of all potential environmental impacts of mining and reclamation, and in light of OTA's 1984 findings on the value of lease stipulations.
33. Require BLM to establish a uniform permit application review procedure that includes documentation of their review of permit applications for compliance with lease stipulations, and require coordination among all agencies involved in leasing and permitting on the development of such stipulations to ensure they provide meaningful guidance on potential reclamation problems.

CHAPTER 1 REFERENCES

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Chapter 2

Technical Summary

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Chapter 2

Technical Summary

INTRODUCTION

A comprehensive national program for the regulation of surface coal mine reclamation was instituted in the late 1970s with the enactment of the Surface Mine Control and Reclamation Act of 1977 (SMCRA; Public Law 95-87) and the promulgation of the permanent regulatory program in 1979. **In the 8 years since SMCRA, substantial improvements have been made in reclamation technologies and methodologies, and the prognosis for the long-term success of surface mine reclamation in the Western United States has brightened considerably.** Yet recent analyses of surface mine reclamation have raised concerns about the adequacy and use of baseline and monitoring data; the accuracy of methodologies for predicting the impacts of mining and the success of reclamation practices; the use of lease stipulations and permit conditions to accommodate uncertainty; the development and introduction of new reclamation techniques; and the status of research on mined land reclamation in the Western United States (2,3,4,5).

This report discusses these issues in the context of permitting and reclamation for the Federal coal surface mining regions of North Dakota, Montana, Wyoming, Colorado, and New Mexico. The report evaluates the quantity, quality, and management of baseline data used to support premining permitting in the context of the SMCRA performance standards, as well as the uses of monitoring data collected during mining and reclamation; the adequacy and reliability of analytical techniques used to predict the impacts of surface coal mining, and to design and evaluate reclamation; and the scope and adequacy of criteria used to judge the success of reclamation in the West. The report also examines a variety of technical issues related to the performance and design standards for reclamation, identifies research needs, and discusses the remaining uncertainties that need to be resolved before predictions can be made about the long-term success of Western reclamation.

BASELINE AND MONITORING DATA

Coal operators collect ***baseline data***—the thorough premining characterization of all surface and subsurface resources on the mine site—to formulate a mining and reclamation plan and permit application. Baseline data provide the basis for predicting the impacts of mining and reclamation and for defining the postmining land use. ***Monitoring data*** are collected during and after mining and reclamation to track the impacts of mining and to refine the reclamation plan, if necessary. Together, these two sets of data enable the operator to compare premining and postmining conditions to evaluate the success of reclamation.

OTA found that *baseline* data generally are adequate for making informed decisions, during permitting, about an individual mine's ability to meet the SMCRA performance standards. However, the limited ability to manage large amounts of baseline and monitoring data and, in a few instances, unreliability of or inconsistencies in data sets, still place limitations on both reclamation in the field and the advancement of reclamation science.

Data Collection

Collection of reliable data for some parameters can be difficult, either because there are natural obstacles to collecting the data, or standardized data collection methodologies are lacking, or laboratory techniques for generating data need to be refined. **Many data inadequacies could be overcome quickly.** For example, the unreliabil-

Photo credit: Jenifer Robison, OTA staff

Most Western surface coal mines are very large, typically covering thousands of acres over the life of the mine. As a result, large quantities of baseline and monitoring data are needed for mine permitting and reclamation evaluation.

ity of some laboratory analysis techniques for generating chemical data about overburden is a serious limitation on the extremely important problem of delineating overburden strata that may be detrimental to revegetation or postmining water quality. It is rapidly becoming apparent that techniques borrowed from soil science are inadequate because of the physical and chemical differences between soil and overburden, and that new tests must be devised. **Work on developing new sampling, sample preparation, and laboratory analysis techniques could produce results rapidly.**

Lack of coordination in data collection and of standardization in collection methods pose an obstacle to meaningful *regional* data compilation and analysis that also could be overcome. These are particularly a limitation on the predictive accuracy of cumulative hydrologic impact assessments (CHIAs) of all existing and anticipated mining within an area. To be valid in the quantitative models used for such mandatory assessments of regional impacts, hydrologic data must be collected throughout the entire region over the same time periods and with the same methods. Statistical techniques currently are used to accommodate differences among data sets, with the magnitude of the predictive error increasing with the magnitude of the differences and the number of assumptions that must be made.

Operators and regulatory authorities are beginning to move toward the necessary standardization. The Wyoming regulatory authority, for example, requires operators in the vicinity of Gillette, Wyoming, to coordinate their groundwater data collection efforts. These operators formed the Gillette Area Groundwater Monitoring Organization (GAGMO), and they collect data on or around October 1 of every year and subsequently publish it for interested parties. **Such coordination of data collection is rare, however, and the operators and regulatory authorities should consider extending it to other areas and disciplines.**

The lack of standardized methodologies for collection of some data seriously limits their usefulness. Standardized surface water quality data collection methods do not exist for ephemeral streams, which comprise the majority of streams in the Western mining regions. Because such streams flow only in response to runoff events, their infrequent and unpredictable flows will continue to limit the availability of data. As a result, the usefulness of ephemeral stream data is severely limited in predictions of the probable hydrologic consequences (PHC) of mining and reclamation and in CHIAs, and it is difficult for regulatory authorities to assess compliance with hydrologic performance standards.

Standardized data collection methodologies also are lacking for wildlife. The mobility and adaptability of wildlife make it unlikely that accurate animal population data suitable for quantitative impact assessments ever will be available. The difficulty in collecting accurate population data has prompted a shift in focus in the wildlife baseline studies required in most States from collection and analysis of population data to the description and delineation of habitat extent and quality. But the development of standard methodologies for quantitative measurement of the various physical and floral features of wildlife habitats has not kept pace. Such standardized collection methods are necessary for the reliable prediction and analysis of wildlife impacts, and for the development of design criteria for impact mitigation measures such as rock piles and nest boxes. Standardization is particularly important when wildlife data are of regional concern, as large mammal, raptor, and game bird data are, because such data have many potential users. At present, impact analyses and mitigation design are based on the professional judgment of wildlife biologists, which has proven accurate in the few attempts at statistical verification based on available population data.

While these data collection problems introduce some uncertainties in the reliability of methods for predicting and evaluating mining impacts and reclamation success, OTA did not find them to to be a large problem in the permitting or monitoring of Western surface coal mines. Their primary effect has been to increase the cost of reclamation due to the need to design for worst-case impacts. It also might be more difficult for regulatory authorities to review permit applications because of the need to verify statistical analyses.

Data Management

The large quantity of data being collected has caused serious data management problems for both mine operators and regulatory authorities. First, data collection has outpaced analysis. OTA found that it is not uncommon for the Office of Surface Mining (OSM) or the State regulatory authorities to require operators to collect data that are never analyzed or reviewed. This problem is most apparent in monitoring data for disciplines that tend to be data intensive (overburden and hydrology), although OTA also found a few instances of lack of analysis of baseline data. SMCRA requires extensive hydrologic monitoring, but **the amount of hydrologic monitoring data operators submit to regulatory authorities is so large that personnel and resources rarely are available to review it.** Only in Wyoming has the regular review of monitoring data become a standard part of the State's annual review of mining operations; even there, available personnel are unable to analyze all of the monitoring data that have been submitted. In many areas, the operators' collection and submission of monitoring data has become perfunctory. **"Scoping" processes to examine which baseline and monitoring data actually are needed for permit compliance and reclamation success evaluations, and subsequent revision of data collection requirements, could facilitate data management and analysis.**

The lack of review or analysis of monitoring data also means that an important opportunity is being lost to validate the analytical techniques used to predict the impacts of mining and to design and evaluate reclamation. Optimizing the quantity and format of such data would facilitate its use in confirming the validity of the predictions based on it.

The problems with data quantity and management are compounded by the format in which data are submitted to the regulatory authorities. The permit applications themselves are a prime example of costly data collection whose utility is circumscribed by an inaccessible format. Western surface mining permit applications typically consist of 25 to 30 3-inch thick 3-ring binders of data (and analysis), all in hard copy, which reside on shelves in regional OSM and State regulatory authority offices. The data generally are not reduced or made computer accessible and, with the exception of more recent permit applications in Wyoming and Colorado, there is no standard format for the applications. As a result, only the preparer of the application and the regulatory agency staff who review it can find information in the numerous volumes without an extraordinary commitment of time and effort. **Although the data in permit applications could be useful to parties other than the permittee and the regulatory authority (for instance, the Bureau of Land Management (BLM) in fulfilling its responsibilities under the Federal coal leasing program), the sheer volume and inaccessible format of the data at best discourage, and at worst prohibit, such uses.**

Data collection and management for permit applicants and regulatory authorities also could be more efficient if the data in the general literature were of uniform quality and format. Data on the soils, geology, hydrology, vegetation, and wildlife of the Western coal provinces are collected by Federal and State agencies, universities, and independent research organizations, but their usefulness in preparing a permit application varies. Most regional data collected by government agencies are too few over too large an area to fulfill permitting requirements, while data from academic and independent research usually have the opposite problem. Much of this information also has quality control problems due to the lack of standardization in the data collection techniques used. In many cases, the data have not been made accessible by computer or published.

Although such data rarely meet all the regulatory requirements for baseline or monitoring data, they may serve as a good starting point. U.S. Geological Survey hydrologic and geologic data and U.S. Soil Conservation Service soils data frequently are incorporated in permit applications but must be augmented with more detailed, site-specific information to meet regulatory requirements. Most of the available vegetation and wildlife information, however, is useful only to provide a preliminary profile of the mine site and to highlight potential reclamation problems or other factors to guide the applicant's data collection efforts.

The large amounts of data in permit applications and the general literature about the resources of Western mining regions have led operators and regulatory authorities to question whether there is significant duplication of data collection efforts that could be eliminated through the compilation of comprehensive, computerized disciplinary databases. **Because the data requirements for permit applications are highly site-specific, OTA did not find redundancy in data collection to be a significant problem *within* the mine permitting process.** However, the development of comprehensive databases from permit applications and other sources would improve the background information available to permit applicants and regulatory authorities.

Because of the data management problems outlined above, OTA did find redundancy *between* permit application and monitoring data and the data collection efforts of other groups. Comprehensive disciplinary databases could eliminate this redundancy. Such databases would be especially useful to Federal and State agencies and research groups working in the areas of hydrology, soils and geology, and wildlife. As mining in the West expands and the amount of permit data collected grows, these groups will continue to repeat permit applicants' data collection efforts if the data in the applications are not made more accessible and useful.

ANALYTICAL TECHNIQUES

Operators and regulatory authorities use a wide range of methods to interpret and analyze data when predicting the impacts of mining and reclamation and in designing reclamation, and the ultimate success of reclamation may depend on the validity of those methods. **Some analytical techniques in use, however, do not consistently produce realistic predictions or valid interpretations with available data, or must rely heavily on assumptions to compensate for data inadequacies.**

Predicting the Impacts of Mining and Reclamation

In predicting the impacts of mining and reclamation, assessments of the quality and quantity of surface and groundwater resources and of the soil resource and the material within the postmining root zone are of major concern because they are critical to the postmining ecology, yet they are subject to a high degree of uncertainty. Impacts on vegetation, and to a limited extent wildlife, are determined indirectly from the predicted characterization of the postmining soil and water resources.

Hydrologic Impacts

SMCRA requires mine operators to conduct assessments of the probable hydrologic consequences (PHC) of mining and reclamation both on and off the mine site, and requires regulatory authorities to perform the CHIAs.[1] The PHC determination covers all potential impacts to surface and groundwater from a single mine, and, historically, has addressed the 5-year term-of-permit mining area. The CHIA expands on PHC determinations to encompass offsite components of the hydrologic system that are likely to be adversely affected by the cumulative effects of all existing and anticipated mines for the proposed life of the mines. PHC determinations and CHIAs use combinations of analytical techniques for predicting impacts on surface and groundwater quantity and quality.

Groundwater Quantity.—The development and use of quantitative methods for predicting impacts to groundwater quantity *during mining*—pit inflows and associated drawdowns—has tended to lag behind other quantitative developments in groundwater science. The effects of this are evident in the wide range of analytical techniques used in the mine permit applications reviewed for this assessment, which varied from simple linear extrapolations based on historical trends to sophisticated computer models. State regulations and guidelines for analysis provide essentially no assistance in selecting the appropriate technique for site-specific conditions.

Where substantial amounts of accurate and consistent data are available, simple linear extensions of historical trends can predict groundwater quantity impacts during mining with reasonable accuracy, provided that no changes are made in mining rates or methods, and no unforeseen boundary effects are encountered. The impact assessments in earlier (roughly pre-1980) permit applications generally are based on one or more of the basic methods available for such linear extensions of historical trends.

The more recent permit applications show an evolution toward the use of more sophisticated mathematical models for predicting pit inflow rates and drawdowns. These techniques usually involve the repetitious solution of several groundwater equations, each suited to a particular aspect of the local hydrogeology or the pit progression, or to both. Because the premining understanding of the groundwater hydrology of the area is incomplete, simplifying assumptions about the hydrologic system and about initial and boundary conditions have to be made.

Relatively simple analytical models are widely known among industry and regulatory personnel and can be duplicated easily, which facilitates regulatory review. However, they cannot account for the wide variations in aquifer hydraulic characteristics and boundary conditions normally encountered in mining, and their results can only reflect a limited range of possible pit configurations and "worst-case" predictions. Their accuracy can be improved by using monitoring data to continually refine the predictions.

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[1] The discussion of PHCs and CHIAs reflects the typical practices in the mine permit applications reviewed for this assessment. Recent court decisions require the regulations governing hydrologic assessments to be revised, and the scope of these assessments may change in the future (see ch. 4).

More complicated numerical flow models are becoming more common among large operators in the West, who have the personnel and resources to use them. Such models are better able to represent the wide range of physical and temporal variations in a system, can incorporate more sophisticated sensitivity analyses, and are not limited by some of the restrictive assumptions necessary for simpler analytical models. However, numerical flow models are time-consuming to set up initially in that they require extensive input data and substantial calibration and verification. They also can be more difficult for the regulatory authority to review without proper documentation. Of 138 numerical models surveyed in 1980, only 20 were fully documented, were not proprietary, and had been applied in the field, and thus met all the requirements for a "usable" model (1).

A continuing problem in most mine permit applications is the applicant's failure to justify, based on its suitability for mine-site hydrogeologic conditions, the selection of a particular analytical technique for predicting groundwater quantity impacts during mining, and to describe the assumptions inherent in the analysis. In many instances, the lack of this information renders the analysis difficult to evaluate even for an experienced hydrologist, and hinders the regulatory authorities' evaluation of the mining and reclamation plan until the necessary documentation is prepared by the permit applicant.

After mining, the geology, geochemistry, and hydrology of the site have been altered, and **it is necessary to predict: 1) the nature and sources of spoils recharge, including postmining spoils aquifer characteristics; 2) the time of spoil resaturation and reestablishment of hydraulic equilibrium; and 3) postmining spoils water quality.** Groundwater recharge to the spoils is difficult to quantify without monitoring data because it is a function of the spatial and temporal distribution of precipitation, topography-runoff relationships, and the unsaturated and saturated hydraulic properties of a spatially heterogeneous geologic environment.

Where field data on spoil hydraulics and groundwater recharge are available—primarily the older mines in Montana and North Dakota—spoil-aquifer hydraulic characteristics and spoils recharge can be measured directly. Unfortunately, few field data have been collected due to the youth of the Western surface mining industry. As a result, most operators must estimate recharge from surface sources using a water budget approach that calculates soil moisture storage and infiltration. They also must predict postmining spoils aquifer flow characteristics using groundwater modeling techniques similar to those outlined above. The regulatory authorities use similar predictive techniques in order to set recharge parameters.

The time required for spoil resaturation and reestablishment of hydraulic equilibrium is a function of both the spoils aquifer characteristics and the sources and amount of recharge. Estimates in the Western mining regions range from as few as 10 to as many as 2,900 years for the replaced spoil aquifers to reach a steady-state condition whereby groundwater flow patterns are fully reestablished. While this introduces uncertainty about the long-term success of hydrologic restoration in some areas, that uncertainty was recognized in SMCRA and not considered so great that mining should be foreclosed in such areas. Continued analysis of field data on spoils recharge would reduce the level of uncertainty.

Groundwater Quality.—The validity and accuracy of predictions of groundwater quality impacts—primarily levels of total dissolved solids (TDS)—are critical because, given the long period of time some spoils may require to become fully saturated and groundwater flow patterns to be reestablished, there may be no way to verify predictions with actual results. Analysis and prediction of postmining groundwater quality impacts are very difficult, however, because the magnitude of such impacts is highly variable, the processes governing water-quality changes are poorly understood, and the processes controlling recharge rates are unknown. As a result, there is little agreement as to the best method for producing consistent, valid predictions.

Most operators in the West measure water-soluble constituents in the spoils and relate those values to observed spoil water quality at the mine site. However, the samples of water and overburden selected for testing and the mixing ratios and contact times may not be representative of postmining conditions. Deterministic models of the chemical processes responsible for the evolution of spoil water quality are under development.

Monitoring programs can be used to verify assumptions made about the trends of spoils-water quality over time. Monitoring will not necessarily provide information on the final postmining groundwater quality, however, because it cannot be assumed that the predictive model itself was valid or that monitoring will be continued throughout the tens to hundreds of years it may take for groundwater systems to establish a postmining equilibrium.

Surface Water.—Surface mining can reduce or augment streamflows, but these impacts generally are not significant in relation to the normal flows in ephemeral and perennial streams in the West (except for the cumulative impacts of sediment control ponds; see discussion of technical issues, below), and the primary concern is the effect of any change in flow on surface water quality. **Surface water quantity and quality impacts are more readily observable than groundwater. Therefore, the analytical techniques for predicting these impacts are less hypothetical and more reliable than groundwater impact predictions.** An exception is the difficulty gathering

Photo credit: Jenifer Robison, OTA staff

Surface water is more readily observable than groundwater. Therefore, premining estimates of impacts on surface water quantity and quality usually are less hypothetical and more reliable than groundwater impact assessments, which are based on predictive techniques that rely heavily on assumptions about groundwater conditions.

data about ephemeral streams, mentioned previously, due to their infrequent and unpredictable flow events.

The greatest potential impact to *surface water quality* from mining and reclamation is an increase in sediment loads, measured as total suspended solids (TSS). In the absence of site-specific data (the usual case for ephemeral streams), a well-accepted method is available to estimate the amount of sediment that will erode from the mine site and be subject to transport downstream during a precipitation event.

Surface water quantity impacts are estimated primarily to support surface water engineering design, and valid statistical techniques are available for computing runoff volumes and peak flows. Deterministic models also are available, but require that assumptions be made about the hydrologic regime of the site; these influence the input parameters and therefore the results. However, **there appears to be no consensus among regulatory authorities on preferred methods for estimating or verifying increases and decreases in streamflows,** and selection of a particular method depends on the capabilities or preferences of the person performing the calculations. As a result, conflicts can arise over the validity of such estimates and the adequacy of the resulting engineering designs. To avoid these conflicts and the potential for expensive redesign, most operators are intentionally conservative in their calculations.

Cumulative Hydrologic Impact Assessments. —A reasonable assessment of impacts to the various components of the hydrologic system can be made at most Western surface coal mines over the life-of-mine area using some combination of available analytical techniques. The predictive accuracy of PHC determinations should improve with time as data become more abundant and more reliable within each permit area due to monitoring as mine development progresses. In areas farther from existing operations, however, fewer data are available about the physical system, and impact assessments are less reliable. **Because of the absence of data from areas in which there is no active mining, and because of the lack of coordination and standardization in data collection mentioned above, the uncertainties are greater in CHIAs than in PHC determinations.**

Regulatory authorities generally require worst-case analyses to compensate for these uncertainties. As uncertainty about the system increases, assumptions made for input to the various analytical techniques become more conservative. Although this strategy avoids errors from underestimating the potential environmental impacts, it may entail other consequences from overstatements of those impacts, including higher reclamation costs.

The uncertainty in CHIAs could be minimized if regulatory authorities used monitoring and repermitting data to check and recalibrate the models used in CHIAs and to assess the validity and sensitivity of the various input assumptions. Periodic sensitivity analyses of the variables would provide valuable information about data inadequacies and could be used in the scoping process mentioned above to focus data collection.

Wildlife Impacts

Among the resources subject to impacts from mining and reclamation, wildlife have certain unique characteristics that make their response to environmental change difficult to predict. Most species are highly mobile, and may move to a new locale for any number of reasons unrelated to mining activity. Wildlife species also are capable of unpredictable responses and varying degrees of adaptation to change, and it is extremely difficult to identify and isolate those responses or adaptations that are directly caused by mining and reclamation from all the other possible environmental factors present. **As a result, quantitative techniques for predicting the impacts of surface coal mining and reclamation activities on wildlife populations are essentially lacking.** Instead, as noted above, these assessments generally are made by intuitive professional judgment based on a knowledge of the operational aspects of the mine and of the ecological resources of the mine site and surrounding area.

Statistical analyses of the effectiveness of wildlife mitigation measures are possible but very

Photo credit: Office of Surface Mining

Wildlife are highly mobile, are capable of unpredictable responses, and may adapt to environmental change. It is extremely difficult to identify which movements and responses are directly caused by mining and reclamation versus all the other possible environmental changes that may be occurring at the same time.

costly. Where such analyses have been undertaken, their results are consistent with these intuitive professional judgments, indicating that **a subjective approach to wildlife impact assessment based on measures of habitat quality from key ecological parameters appears to be a satisfactory way to predict impacts on wildlife resources.**

Revegetation

Revegetation analyses focus on predicting the success of revegetation. **While OTA found little emphasis on the development or use of analytical techniques for predicting long-term revegetation success, the lack of quantitative models does not appear to diminish the potential for accurate predictions.** The most common, and probably most valid available technique for predicting revegetation success is to consider results of the most recent technology at other mining operations in the region with similar soil, overburden, and climatic characteristics, under the usually valid assumption that, given similar environmental factors, the results of particular revegetation and other reclamation methods will be similar.

There are two problems with this approach, however. First, there are few vehicles for disseminating information on the results of different revegetation techniques. Indeed, some companies may be reluctant to share such information for competitive reasons. Second, some techniques may show initial promise but poor results over the long term, and vice versa. The former may be adopted at several mines before their long-term problems are fully understood, while the latter may be rejected prematurely. A continuing commitment to research on the long-term success of various revegetation techniques for different ecological regimes in the West, and means of disseminating the results of that research, are needed to resolve these problems.

Analytical Techniques Used in the Design of Reclamation

Accurate characterization of the overburden and delineation of potentially deleterious overburden material, design of an optimum soil-salvage plan, design of well-stabilized stream channels, and design of efficient sedimentation control measures are important factors in the ultimate success of reclamation. When design rather than performance standards are used to determine reclamation success, the importance of the reliability of the techniques used to design reclamation is heightened.

Overburden Characterization

Overburden—all material between the soil and the coal resource, including bedrock or other rock material—forms the basic material for the reclamation process. Therefore, the chemical and physical character of the overburden are key factors in determining impacts on postmining spoils hydraulics and water quality, as well as revegetation success. However, the geology of the overburden in many of the mining regions of the West is highly variable and/or complex, the science of overburden characterization is neither old nor well-established, and the overburden is not easily observed.

As a result, **analysis of the physical and chemical properties of overburden is difficult. Even with a low drilling density and vertical sampling intensity, thousands of overburden data points will be generated at the average Western surface mine. There are no well-established procedures for interpreting these data to determine the chemical suitability of the overburden materials.** Most available laboratory methods for generating chemical suitability data were developed for soil characterization and have proven unreliable when applied to overburden. Also, while acid formation is recognized as a possible problem in some areas of the West, available tests have proven inaccurate in determining the acid-base potential of Western overburden (see below).

The State regulatory programs exhibit wide variation in their requirements for chemical analyses. The methods for characterizing overburden and for handling potentially deleterious materials generally are determined on a case-by-case basis. The primary risk is the cost of reconstructing an area if such materials are not identified prior to backfilling.

Soil Characterization

The redressed soil serves as a chemical and physical buffer between the disturbed mine spoil and surface water, vegetation, and wildlife resources, and also is a critical element for successful reclamation. Most undisturbed soils are in relative chemical and physical equilibrium with the surface environment, and thus are less likely to be sources of exceptional release of sediments or toxic elements than disturbed soils. Ideally, the restored soil material also will be in approximate equilibrium with the surface so that unforeseen and undesirable chemical and physical changes will not occur. Therefore, the operator must determine the premining physical and chemical character of the soil and the amount of suitable soil available for redressing, and must design a redressing plan to ensure physical and chemical suitability and stability of the postmining soil.

Soils are relatively easy to observe and the science of soil characterization is well-established. Each State regulatory authority has developed unsuitability criteria for soils that generally accommodate the differences in reclamation objectives or emphasis that occur from site to site. A low sampling density can result in significant errors in estimating the volume of salvageable soil material, however.

In the Western coal regions, where natural soils in many areas are typically thin and marginally productive, optimization of the soil resource is essential. Most State soil inventory and handling requirements make it more likely that the best available soil will be used to provide an adequate root zone and to minimize impacts from potentially deleterious overburden materials occurring in that zone. However, **State programs that require salvage of *all* suitable soil ma-**

Photo credit: Jenifer Robison, OTA staff

The redressed soil serves as a physical and chemical buffer between the disturbed mine spoils and the surface water, revegetation, and wildlife resources, and thus is a critical element for successful reclamation. In the Western coal regions, where natural soils in many areas typically are thin, optimization of the soil resource is essential.

terials and redressing in uniform thickness may not promote optimization of the soil resource in all mining and reclamation situations, and may add unnecessarily to reclamation costs. Lack of consideration of the soil's organic and biological suitability—especially in deep soils—can detract from optimization of soil quality for revegetation unless the topsoil and subsoil are handled separately (two-lift topsoiling).

The regulatory requirement for uniform topsoil thickness in redressing at each mine facilitates inspection and enforcement, but ignores the fact that topsoil depth varies naturally as a function of topography and vegetation types. Thus landform position may be as important as depth for some vegetation species. The soil thickness required to reach maximum plant production also varies with average effective precipitation, depending on the soil and vegetation type. Furthermore, redressing uniform topsoil thickness can discourage direct-haul topsoiling in areas where premining soil depths vary naturally. Although non-uniform thickness is common over an entire site postmining, each parcel or reclaimed unit generally has uniform thickness. Additional regulatory flexibility in this matter, on a case-by-case basis, could facilitate achievement of vegetative diversity in many areas (see below).

Design of Restored Surface Drainage Systems

Replacement of an erosionally stable surface drainage system is critical to the long-term success of surface mine reclamation. A number of valid approaches to design are available, from direct field measurement of channel cross-sections and profiles with duplication of the undisturbed channel, to computer-assisted, detailed hydraulic analyses. **In the case study mines reviewed for this assessment, the amount of detail in such**

designs ranged from virtually none to very elaborate geomorphic and hydraulic studies, although an encouraging trend toward a comprehensive, multidisciplinary approach to design of surface drainage systems was observed. Greater attention to design in permitting could reduce the potential for costly repairs of erosion damage during reclamation.

Mines that cover large areas or contain watersheds must be concerned not with just the design of restored channels but with the reconstruction of entire drainage basins. The goal in this case is to attempt to create a new steady-state by manipulating the surface, slope, and channel configuration so that the newly formed system will be in approximate equilibrium with the surrounding area with respect to erosion and sediment transport processes. The premining geomorphic analysis generally is modeled after classical concepts, and the relationships developed in that analysis are applied to the design of the postmining drainage system. However, improper applications of even the most well-understood analytical techniques have resulted in incomplete or incorrect designs. Furthermore, when the overburden-to-coal ratio is very large or very small, the postmining drainage basin characteristics may differ substantially from the premining characteristics, further complicating the design problem.

Hydrologic and Sediment Control Structures

Techniques for the design of hydrologic and sediment control facilities have changed very little since SMCRA, although there has been an increasing use of computers in design, and a gradual standardization of estimating techniques for runoff and sediment. The techniques in use accommodate the lack of site-specific data for sediment erosion and transport rates by providing relative estimates for comparison of alternative designs. Use of a computer allows faster and more accurate analysis than hand calculations, so larger areas can be simulated in greater detail and over shorter time steps. **Monitoring data could be used to calibrate the models used, but OTA found little indication that this is occurring.** Issues related to the use of sediment control ponds are discussed under "Technical Issues," below.

Designing Reclamation of Alluvial Valley Floors

SMCRA allows mining in alluvial valley floors (AVFs) only if they are not significant to farming. Because only 7 years have elapsed since the implementation of the permanent Federal regulatory program, however, no AVFs not significant to farming have yet been completely mined and finally reclaimed under the SMCRA standards, although several plans for the restoration of such AVFs have been approved by the regulatory authorities.

The premining hydrologic studies required for AVF areas under SMCRA are unique in the surface mine permitting process in that they must include an analysis of the relationships between surface and groundwaters and land use, soil characteristics, and vegetative productivity. Thus AVF restoration combines some of the more rigorous design aspects of surface and groundwater restoration discussed previously. **The criteria for premining analysis of the essential hydrologic functions of AVFs and postmining evaluation of AVF reclamation are relatively standardized among the regulatory authorities of the Western States. These criteria are based on accepted engineering and hydrogeologic principles, and the probable success of reclaiming AVFs is viewed by the industry and the regulatory authorities with confidence.** As with hydrologic restoration in non-AVF areas, however, it may be decades or centuries after mining and reclamation before the success of hydrologic reclamation in AVFs can be assessed completely.

EVALUATING THE SUCCESS OF RECLAMATION

Few aspects of the process for final evaluation of reclamation success have been firmly established under the Federal or State regulatory programs. The five States studied in this assessment have established criteria for evaluating reclamation for Phase I of bond release (backfilling the pit, and in some cases, redressing soil), but not for Phases II and III (preliminary revegetation and full release). Furthermore, most existing evaluation techniques and standards have serious limitations, especially for hydrology and revegetation—the two areas emphasized in the SMCRA performance standards.

To date, **no method for evaluating revegetation has been developed that adequately addresses both temporal variations in environmental conditions** (i.e., seasonal and annual climatic variations) **and the spatial diversity that occurs over large areas.** There is general agreement that revegetation standards should incorporate, or be able to be adjusted for, climatic and temporal variations. The most practical method for achieving such adjustment has been to use standards based on reference areas, but such standards are based on the assumption that the vegetation on a few acres can adequately represent revegetation over hundreds or thousands of acres. Furthermore, although the predominant postmining land use in the study area is native rangeland, little test grazing has occurred on revegetated areas as yet. Of the five States, only Montana has established guidelines for test grazing plans and data collection.

The methods for evaluating hydrologic restoration are even more unclear. **Although the SMCRA performance standards emphasize hydrology, most past experience in judging reclamation has concentrated on revegetation success.** The tens to thousands of years that may be required to resaturate spoil aquifers in some parts of the study area make it impractical to measure either spoil water quantity or quality directly. Thus evaluations will have to be made with incomplete knowledge and available predictive tools. Similarly, because surface drainage systems are designed to accommodate peak flows that may occur only once every 10 to 100 years, many channels are unlikely to experience peak flow events during the bond liability period, necessitating the use of predictive techniques and design criteria for evaluation.

It is unclear whether successful revegetation and hydrologic restoration are sufficiently reliable indicators of success for the other disciplines—soils, overburden, and wildlife. Of particular concern is the potential for materials adverse to vegetation to appear in the root zone long after the regraded spoil is sampled, and the topsoil redressed and revegetated. If the presence of such material becomes evident before bond release, it may require expensive rehandling or total reconstruction of the reclaimed soil and overburden, and repetition of the revegetation process. If it appears after bond release, it is unclear how it would be mitigated and by whom. A similar concern is raised by the potential for unsuitable material to be inadvertently placed in the recharge zone, with the water quality impacts not becoming manifest until after final bond release.

TECHNICAL ISSUES IN WESTERN SURFACE MINE PERMITTING AND RECLAMATION

OTA's assessment of surface mine permitting and reclamation in the West highlighted several technical issues that are affected by many of the data and analysis concerns summarized above, and that have significant implications for the long-term success of Western reclamation. These issues encompass the technologies, data, and analytical methods for determining the potential for acid formation in overburden, the impacts of sediment control methods, the effects of soil handling methods on revegetation, the potential for meeting woody plant revegetation standards, the designation and implementation of postmining land uses, and the value of landscape diversity.

Acid Potential in Western Mine Spoils

In characterizing overburden for the planning of reclamation, one objective is to identify potentially acid-forming materials that could become detrimental to revegetation. Acid formation in mine spoils is a common problem in the

East, where the climate is relatively humid and recharge rates for groundwater systems are relatively large, which accelerates the oxidation of sulfur compounds in the spoils and the formation of sulfuric acid. Moreover, in the East, there is little lime in the overburden to serve as a buffer. **A test based on leaching of overburden samples with hydrogen peroxide to extract sulfur forms is used to predict the acid-base potential (ABP) of overburden material in the East.**

The potential for acid formation is much lower in the West because the climate generally is arid or semiarid, and because Western overburden typically has a high buffering capacity. **There are conditions, however, under which acid formation will occur in the West, primarily in portions of the Powder River Basin and in New Mexico. The Eastern method for determining ABP has produced unreliable results in the West** because it assumes that all sulfur forms will be completely oxidized—an assumption that may not be valid in the West where a large fraction of the sulfur occurs in less reactive, organic forms. An alternative test used in Wyoming allows isolation of the reactive inorganic sulfur compounds, but still assumes that all reactions go to completion. **As a result, estimates of ABP in the West may be inaccurate and can result either in a failure to identify materials that need special handling, or in operators being required to special handle some overburden materials unnecessarily.**

Research currently being funded by the Western mine operators, both jointly and individually, is making progress in resolving this problem, and the regulatory authority in at least one State, Wyoming, is prepared to rewrite State guidelines to reflect any changes in analytical techniques or overburden suitability criteria that may result from this research.

Sediment Control

Sedimentation in streams results from accelerated erosion caused by removal of the vegetative cover; topsoil stripping; and construction of stockpiles, roads, and other mine facilities. The Office of Surface Mining has taken the position that the best currently available technology to control sedimentation is a properly designed and constructed sedimentation pond. Construction of sedimentation ponds is governed by both design and performance standards adopted by each State, which generally require that the pond be designed to meet effluent standards established under the Clean Water Act.

Sedimentation ponds are expensive to build and maintain, and they increase the amount of land that must be disturbed during mining and reclamation. The water discharged from sedimentation ponds also is unnaturally clear and therefore can result in erosion and channel degradation downstream in ephemeral streams, which have a naturally high sediment content. Moreover, the cumulative effect of water storage in sediment control ponds at multiple mines in one area can be a significant loss of water—the West's most scarce resource—to downstream users.

Alternate means of maintaining sediment production at or below the level produced from undisturbed terrain are available, including preventive measures that retard the velocity and reduce the quantity of runoff, thus reducing erosion rates, and remedial designs that reduce erosion by avoiding sensitive areas and increased sediment deposition. In addition to mitigating the impacts

Photo credit: Office of Surface Mining

Erosion and associated sediment production are natural processes in the Western United States, but few data are available on natural erosion and sedimentation rates from undisturbed areas. These data are needed to demonstrate that alternate means of sediment control are as effective as sedimentation ponds.

of sedimentation ponds noted above, the alternate control methods can aid revegetation by reducing runoff and thus increasing soil moisture, and by reducing erosion. They also eliminate the risk of sediment pond dam failure. **Such alternate sediment control techniques are considered proven technology and have been implemented successfully in agriculture, highway construction, and other land-disturbing activities.**

Two sets of data are needed in order to demonstrate that alternate means of sediment control are as effective as sedimentation ponds: empirical data on sediment yields (the total amount of eroded material that reaches a control point) **and on natural sediment concentrations in streams, and monitoring data from areas where alternate means are in use.** The data on sediment yields and concentrations could be obtained during baseline and monitoring studies, but OTA found little evidence that anyone is gathering such data. Two mines in Wyoming currently are collecting data from experimental practices undertaken to demonstrate that alternate control measures are equally effective in controlling sedimentation as ponds and thus are adequate to protect water quality in ephemeral streams.

As the needed data become available, regulatory authorities could become more flexible in interpreting design and performance standards for sediment control in discharges to ephemeral streams where a permit applicant is able to demonstrate that proposed controls will be at least as effective as sedimentation ponds. Discharges to perennial streams, however, still will require sedimentation control ponds to protect their naturally high quality water.

Soil Handling and Revegetation

Recognition of the relationship between soil quality and revegetation success—the primary criterion for reclamation success—has produced substantial innovation in soil handling methods. **The results of long-term studies of the effects of topsoil stockpiling indicate that it adversely affects the success of revegetation efforts. Direct haul topsoil, on the other hand, preserves the biologically active component of the soil and enhances maintenance of nutrient cycles. This improves the establishment of planted and volunteer species and can produce superior lifeform and species diversity within a relatively short time. Recent research indicates that, under certain conditions, combining direct haul topsoil with other innovative reclamation techniques can further enhance revegetation success.** Because the direct haul technique eliminates the middle step in the process of stripping, stockpiling and respreading topsoil, it can be less expensive depending on haul distances.

Research in deep soils in Montana and North Dakota also has shown that careful identification and separate handling of the biologically most active surface soil layers, without dilution by underlying subsoil—"two lifts"—can improve revegetation sufficiently to justify the cost. **The limited monitoring data available suggest that the combination of two lifts with direct hauling may produce the best results in reestablishing rangeland diversity, and in some areas may be enhanced even further by the use of mulch produced from native vegetation.** No research data comparing these and other methods for different geographical areas are available to verify these hypotheses, however. As noted previously, **greater flexibility in the Federal and State regulations on topsoil salvage and redressing thickness could promote optimization of the soil resource in permitting and implementing soil handling for revegetation.**

The Revegetation of Woody Plants

Woody plants—shrubs—are ecologically important in the Western United States as forage and cover for livestock and wildlife, and for improving soil moisture conditions and protecting herbaceous plant species. In some combinations of slope and substrate, woody plants also may improve slope stability because their more extensive root systems can anchor a greater volume of material than many herbaceous species. Because of these considerations, the revegetation requirements in SMCRA, the regulatory program performance standards, and the standards for revegetation success are tied, in part, to the reestablishment of native woody plant species of the same type and density that existed on the site before mining.

Photo credit: Office of Surface Mining

High premining shrub density can be difficult to reestablish, even with the most advanced revegetation techniques. Lower overall shrub density, in high-density groupings based on habitat mapping, can provide as valuable wildlife habitat as uniform densities while preserving the quality of land for livestock grazing.

Tying woody plant density standards to the premining density raises several concerns, especially in areas where the premining density is relatively high (primarily Wyoming, Colorado, and New Mexico). First, **even with the most advanced shrub establishment technology, there is little field evidence that high densities can be reestablished over an entire reclamation site during the 10-year liability period.** In the sagebrush-steppe ecosystems which occur in the northern part of the study area, operators have found it difficult to establish any shrubs other than fourwing saltbush, with big sagebrush being especially difficult. In these ecosystems, the prospects of meeting the proposed Wyoming regulatory standard of one stem per square meter on 10 percent of the area may depend on which plant species are counted as shrubs for density purposes.

Second, **while shrubs in moderate to high densities improve habitat quality for a variety of animal species, uniformly high woody plant density can detract from the quality of land for livestock grazing.** Woody plants provide critical winter food and cover for wildlife species with a high recreational and economic value in the West (particularly pronghorn antelope, deer, elk, and sage grouse). But cattle, and to a lesser extent sheep, prefer herbaceous vegetation to shrubs. As a result, ranchers have undertaken large-scale programs to thin or kill sagebrush and other woody species on rangelands, frequently with financial or physical support from BLM's rangeland management programs. If a postmining landowner undertakes such range management, it negates the purpose and expense of reestablishing woody plant density. For the most part, this conflict can be traced to the lack of specificity in designation of the postmining land use (see below) and to inadequate coordination among Federal and State regulatory authorities and land management agencies.

Many State regulatory and mining industry personnel feel that lower overall shrub densities, if accomplished in high-density groupings based on premining habitat mapping, provide as valuable wildlife habitat as uniform densities at high premining levels. In this context, rangeland management programs also can benefit wildlife if done selectively. For example, thinning big sagebrush to increase herbaceous production can improve the forage for pronghorn as long as shrubs remain available in critical winter browse areas and are not totally removed from summer range. **This approach to mitigating the conflicts between the forage and cover needs of different livestock and wildlife species has begun to be recognized in the West** (e.g., the proposed Wyoming standard). However, uniform high shrub density standards still are the norm in most areas.

Postmining Land Use

SMCRA and the regulatory programs require detailed characterizations of the premining and postmining land uses in the permit application and reclamation plan. These characterizations must include ***quantification*** of the capability of the land prior to any mining to support a variety of uses considering soil and foundation characteristics, topography, and vegetative cover; and of the premining productivity of the land, including the average yield of food, fiber, forage, or wood products obtained under high levels of management.

Despite these requirements, the characterization of pre- and postmining land uses is at best perfunctory in most of the permit applications reviewed for this assessment. A number of the applications contained land use characterizations with little more information than the statement: "The premining land use is grazing and the postmining land use is grazing." In some cases, this lack of specificity can be attributed to inadequate baseline information in the permit application. In other cases, it is the fault of the Federal surface management agency (e.g., BLM, U.S. Forest Service), which is required to determine, or at least consent to, the postmining land use.

Lack of specificity and quantification in describing pre- and postmining land uses can adversely affect postmining vegetative and landscape diversity, the implementation of surface owners' or management agencies' land use recommendations, and the difficulty and cost of reclamation. Moreover, at mines where reclaimability is an issue during permitting, a much more rigorous approach to characterizing premining land uses and to predicting the capability and productivity of the reclaimed surface is necessary before findings of reclaimability can be made objectively.

Regulatory authorities should enforce the requirements for pre- and postmining land use characterization more strictly. For privately owned lands, the land use description and the quantification of capability and productivity must remain the responsibility of the permit applicant, with the cooperation and concurrence of the landowner. For public lands, BLM and the Forest Service currently are preparing land use plans that should provide the basis for quantitative characterizations of pre- and postmining land uses. Until these documents are completed, **Federal surface management agencies should ensure, during their review of permit applications and reclamation plans, that careful attention is paid to the applicants' quantitative characterization of pre- and postmining land use, productivity, and capability.**

Implementation and management of the postmining land use after bond release raises issues about changes in land use and conflicts among land uses. At some mines, **conflicts arise between land uses—particularly between agricultural**

uses and wildlife habitat—because the surface owners, usually farmers or ranchers, desire that all land be returned to cropland, pastureland, or grazingland. This conflict is common in States where reclamation standards for native rangeland and wildlife habitat (e.g., woody plant density standards and overall vegetative diversity) are more difficult to attain than those for other land uses, such as pastureland.

Another concern is **the lack of incentives for post-reclamation landowner or manager compliance with land management plans.** Even the best reclamation methods can be negated quickly by postmining land management decisions or techniques (e.g., overgrazing, range mismanagement), leaving the operator open to allegations of reclamation "failure." This underscores the importance of restoring the land's capability, rather than a narrowly defined "use." Moreover, there are no regulatory mechanisms to ensure that the surface owner will not convert lands reclaimed for one use (especially wildlife habitat) to other uses after bond release.

Landscape Diversity

The concept of "landscape diversity," which encompasses the entire ecosystem, recognizes the mosaic nature of Western landscapes resulting from localized differences in the physical environment, plant communities, wildlife populations, and land uses. Strict application of a full restoration concept might be inflexible in its ability to adapt to changing technology and to climatic and other uncontrollable variables. Moreover, full restoration of landscape diversity would go beyond the premises of SMCRA in focusing on the long-term quality of reclamation, rather than rehabilitation of the land to a particular level of viability specified in the permit or in the criteria for reclamation success. Somewhere in between is an approach that ensures long-term ecosystem function and viability, and that requires restoration of features that were critical to the premining ecosystem, but allows flexibility in the means of achieving such restoration. Implicit in this approach is an understanding that ecosystem dynamics change over time, and a reclaimed site cannot achieve a natural level of equilibrium with the surrounding area in the 10-year bond liability period.

No statewide requirements for full restoration of landscape diversity currently exist in the Western States studied, although requirements for specific mines have been established on a case-by-case basis, primarily in relation to vegetative communities. The restoration of ponderosa pine woodlands in Montana, woody draws in Montana and North Dakota, sage grouse strutting grounds in Montana, and wetlands in North Dakota are examples of reclamation that attempts to preserve features that contribute to landscape diversity.

Surface features that have been eliminated include rimrock and escarpments, ridges, badland topography, and "microsites" (small premining surface features important to premining hydrology or wildlife habitat). **In some cases, it is impossible to reestablish a particular landform.** For example, hogback ridges and badlands are supported by strata that would be removed during mining, precluding their reestablishment on the reclaimed surface. Moreover, disturbance of some badland strata can result in physical and chemical changes that significantly affect erosivity. In other cases, **restoration of landforms may be too costly or difficult for all but the most elaborate reclamation plans.** Microsites, for instance, often are dependent on hydrologic, soil, or overburden characteristics that are very expensive to duplicate with available mining and reclamation equipment.

Finally, **some regulatory requirements may actually discourage diversity in some mining and reclamation situations.** The SMCRA requirement to return mined areas to their approximate original contour typically has resulted in gently undulating land with little topographic variety, because the features that provide diversity frequently are the most difficult to design and reestablish. Requirements for uniform topsoil depths over the regraded surface and for uniformly high revegetation density further homogenize site conditions and limit the ability to restore full vegetative community diversity.

However, the postmining topography can be designed to *mimic* premining features such as rimrock and microsites. Variances have been granted at a few mines for sections of unreduced highwall as a means of leaving artificial cliffs or bluff extensions that simulate the original premin-

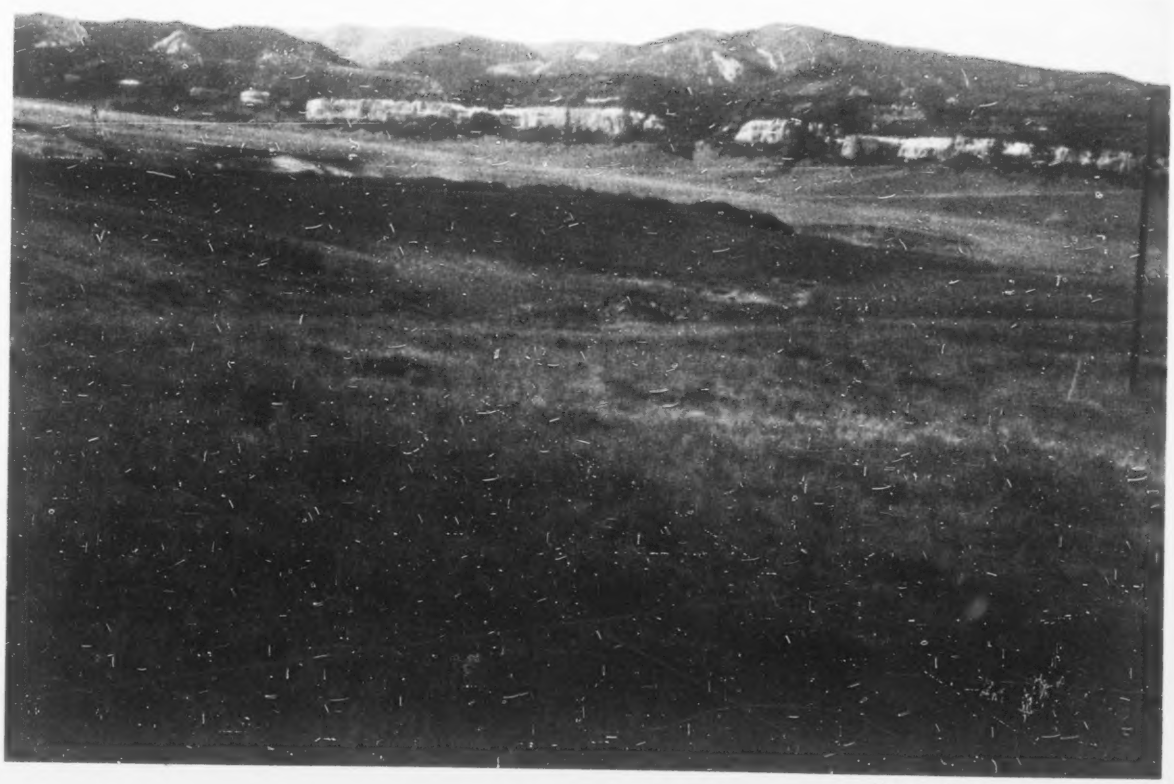

Photo credit: Jenifer Robison, OTA staff

The regulatory requirements to return mined areas to their approximate original contours and to reduce all highwalls typically have resulted in gently undulating land with little topographic variety (foreground). Surface features that are eliminated by mining include rimrock (background), which provide nesting sites for eagles and other raptors, habitat for small animals, and aid in moisture retention near the base.

ing features and aid in the accumulation of additional surface moisture near the highwall base. The restoration of microsites and features such as playas and prairie potholes may be expensive, but some mines are restoring them to preserve or enhance wildlife habitat.

If attention is to be paid to landscape diversity, it needs to begin with the reclamation plan and permit application. A full consideration of geomorphology would require integrated analyses of the consistency among the postmining topography, the hydrologic characteristics of the reconstructed soils, the revegetation communities, the reconstructed drainage systems, the proposed postmining land use, and the geomorphology of the contiguous areas. Thus baseline data collection would provide an interdisciplinary ecological characterization of the proposed mine area that could be used in the design of a diverse postmining landscape, as well as a set of numbers to demonstrate that the performance standards will be met. **Promoting such an interdisciplinary approach to design and implementation of landscape diversity would require some additional effort, and thus cost, both in premining baseline studies and specification of the postmining land use, and in implementing the reclamation design. Long-term research efforts are needed to demonstrate whether the potential benefits of such an approach for the quality of reclamation would outweigh the costs.**

Photo credit: Office of Surface Mining

The postmining topography can be designed to mimic premining features. For example, portions of unreduced highwall have been used at some sites to substitute for rimrock lost to mining.

TECHNOLOGICAL INNOVATION AND RESEARCH

Since the first State reclamation laws were enacted in the early 1970s, mining companies, a wide range of Federal and State agencies, universities, and other organizations have undertaken a significant amount of research and developed a variety of new techniques for reclaiming surface mined lands in the arid and semiarid regions of the West. Historically, revegetation has been the principal subject of research at Western surface mines, primarily because the regulatory standards for reclamation success focus on revegetation success. This emphasis is now shifting toward hydrology, soils, and overburden as the complexities in these systems are recognized.

Most of the reclamation-related research programs sponsored by Federal agencies were discontinued in the late 1970s or early 1980s, primarily for budget reasons, but also because the responsibility for the majority of such research was consolidated within OSM. Of the discontinued programs, the most extensive were conducted by the U.S. Forest Service's Surface Environment and Mining Program (SEAM) and the Bureau of Land Management's Energy Minerals Rehabilitation Inventory and Analysis (EMRIA). The failure to transfer funding for these programs to OSM meant not only the loss of over 150 research and development projects, but the discontinuation of valuable data sources: SEAM compiled a quarterly computerized listing of reclamation studies related to the Rocky Mountain West (the only bibliographic reference of its kind), while EMRIA gathered information about the reclamation potential on coal lease tracts and developed lease stipulations to assure the achievement of reclamation goals for Federal coal lands.

OSM has only two basic vehicles for research under SMCRA: the State mining and mineral resources and research institutes, and the Abandoned Mine Land (AML) reclamation program. The Federal share of AML funds has yet to be allocated, and co-funding for the mineral and resources research institutes was discontinued in fiscal year 1982, although specific applied research projects continue to be funded by OSM, either alone or in cooperation with other agencies. The OSM budget for such projects has declined from a peak of around $1.47 million in 1981-82 to a request for $970,000 for fiscal year 1986, of which almost half was allocated to subsidence control and coal wastes (primarily Eastern or abandoned mine reclamation problems), and one-fourth to staff and administrative support. **Attention should be paid to the allocation of available funds and priorities for research among Eastern, Midwestern, and Western reclamation problems.**

To compensate for inadequate Federal research funding, OSM treats experimental practices and permit conditions at active reclamation sites as substitutes for research. Under SMCRA, experimental practices were intended to encourage advances in mining and reclamation, or to allow special postmining land uses, if they potentially provide as much environmental protection as the performance standards and are no larger or more numerous than necessary to determine the effectiveness and economic feasibility of the practice. Of the five experimental practices approved for the Rocky Mountain West since 1979, two (ongoing) address alternative sediment control; one (completed in 1982) was a court-ordered compromise on a variance for an excess spoil disposal area; one (still undergoing monitoring) involves a variance from approximate original contour in order to leave a portion of a highwall to preserve eagle nests; and one (ongoing) allows the disposal of mine spoil offsite to suppress an underground fire at an abandoned mine.

OSM personnel have indicated that they would like to see more applications for experimental practices. The permitting and monitoring requirements are so difficult and expensive to meet, however, that few companies are willing to undertake an "experiment" that can only be implemented on a portion of the mine site unless the potential long-term economic benefits of demonstrating the effectiveness of the practice are substantial. Moreover, OSM approval of an experimental practice takes so long that the mine usually proceeds beyond the area where the practice might have been effective long before it can be permitted. Establishing strict schedules for OSM approval of experimental practices could alleviate this problem.

Under a more flexible regulatory system, the experimental practices listed above might have been handled through site-specific variances or permitting of alternative reclamation techniques, or under the AML program. If applications for such variances or techniques are not approved, however, additional time and money is required to revise the permit application and reclamation plan. Moreover, permit applications requesting such variances still must be approved by OSM, which can require that the proposed reclamation method be permitted as an experimental practice or not allowed. **These possibilities pose major constraints on innovation in reclamation methods.**

Mine operators also have conducted applied research on specific reclamation situations, either to aid in the design of reclamation, or to meet or develop bond release criteria. Frequently, such applied research projects are the result of permit stipulations that require the collection and analysis of monitoring data or the development of criteria for judging the success of particular types of reclamation. Ongoing research at Western mines from all sources of funding is shown in table 2-1.

While significant advances have been made in Western reclamation technologies, and the prospects for the long-term success of reclamation in the West have brightened considerably, OTA identified a number of areas in which additional research or analysis still is needed. These include:

1. development or improvement of techniques for the collection of baseline and monitoring data, especially improved laboratory techniques for generating data about overburden chemistry, and standardized methods for collecting hydrologic and wildlife data;

Table 2-1.—Summary of Ongoing Research and Innovation at Case Study Mines[a]

Soil and overburden	Surface and groundwater	Revegetation	Wildlife
North Dakota: ND-A: Special handling of clayey soils for wetlands ND-D: Landform position and mixing of soil types to aid moisture retention in prime farmland —Effect of soil type on soil/spoil interface for optimum moisture-holding capacity	***North Dakota:*** ND-A: Restoration of wetlands	***North Dakota:*** ND-A: Transplanting native vegetation plugs for reestablishing wetlands ND-D: Restoration of woody draws —Planting, cultural and management practices for achieving grassland diversity —Irrigation, grazing, mulch, seed mixes, and topsoil handling and depth studies	***North Dakota:*** ND-A: Reconstruction of wetlands —Developing criteria for the success of wetland habitat restoration —Restoration of woody draws and native prairie on an "acre-for-acre" basis ND-D: Reconstruction of woody draws for wildlife habitat
Montana: MT-B: Retention of highwall portion as bluff extension —Use of scoria and similar soil over compacted overburden for ponderosa pine substrate —Monitoring vegetation trace metals contents to judge the success of soil reconstruction —100 percent two-lift direct-haul topsoiling MT-D: Sodium migration from sodic and clayey overburden —Topsoil erosion runoff plots	***Montana:*** MT-B: Extensive site-specific and regional groundwater database —Special handling of overburden to protect water quality MT-C: State-of-the-art PHC and CHIA analyses for proposed mine adjacent to perennial stream classified as an AVF MT-E: Management and use of very large hydrologic database —Spoil aquifer hydraulic analyses	***Montana:*** MT-A: Ponderosa pine reestablishment MT-E: Reestablishment of ponderosa pine —Coulee bottom restoration —Sodding of native grassland —Special soil handling for landscape diversity —Topsoil depth, surface manipulation, native species, legumes, phased seeding, shrub reestablishment, native hay mulch, temporary stabilizer crop, and fertilizer studies	***Montana:*** MT-D: Relocation of sage grouse strutting ground —Nest box program for American kestrels —Use of radio-telemetry and other methods to develop monitoring data to determine when impacts are due to mining versus natural variation in populations —Landscape diversity through replacement of microsites —Identification of preferred forage plants through fecal analyses to develop seed mix
Wyoming: WY-A: Detailed highwall map from stratigraphical-geochemical correlation —Intensive overburden sampling to delineate acid-forming and other deleterious strata as well as wet areas, defining highwall stability, planning shovel moves, etc. WY-B: Composite sampling of regraded spoils —Watershed erosion monitoring WY-D: Nonuniform topsoil thickness —Acidic spoil treatments —Erosion monitoring —Reclaimed geomorphology —Monitoring swell and settling WY-G: Two-lift direct-haul topsoil in desert ecosystem —Use of boron-tolerant species WY-K: Nonuniform topsoil thickness	***Wyoming:*** WY-C: Potentially acid-forming overburden WY-E: Computer modeling to predict groundwater impacts WY-G: Alternative sediment control experimental practice —State-of-the-art streamflow sampling WY-H: Restoration of essential hydrologic functions of an AVF WY-K: Formation of surface drainage channels through erosion and deposition	***Wyoming:*** WY-A: Effects of nurse crop on establishment of perennials —Effects of grazing on species composition —Mulching —Use of sagebrush "potlings" WY-C: Annual grains grown as source of soil organic matter WY-D: Methods to reduce competition between vegetation species —Planting cottonwoods in drainages WY-G: Need for irrigation in arid area WY-K: Annual rotation of experimental species WY-I: Reconstruction of a playa	***Wyoming:*** WY-J: Experimental practice to leave a highwall portion for raptor habitat

Table 2-1.—Summary of Ongoing Research and Innovation at Case Study Mines[a]—Continued

Soil and overburden	Surface and groundwater	Revegetation	Wildlife
Colorado: CO-B: Aerial and field surveys to monitor swell factors for postmining topography CO-D: Shredded mountain shrub vegetation as mulch in direct-haul topsoiling —Erosion monitoring	***Colorado:*** CO-C: Experimental practice for valley fill for excess spoil disposal CO-F: Burial of powerplant wastes in backfill	***Colorado:*** CO-A: Reclamation of pinon-juniper on massive sandstone CO-D: Live mulch for woody plant reestablishment and complete topsoil removal —Direct transplanting of tree and shrub pads using modified bucket —Omitting seeding of direct haul topsoil CO-E: Use of snowfences for water harvesting —Mulch studies CO-F: Direct transplanting of mature native shrub pads	***Colorado:*** CO-D: Detailed characterization and delineation of physical and floral features of elk calving habitat CO-F: Reestablishing premining land uses on postmining topography to facilitate best management practices
New Mexico: NM-B: Use of overburden as topsoil substitute —Use of topsoil quality evaluation system NM-D: Nonuniform topsoil thickness over spoil of varying quality —Sodium migration in a very low precipitation regime —Burial of fly ash with elevated selenium levels	***New Mexico:*** NM-C: Comprehensive erosion monitoring program NM-D: Burial of powerplant wastes in backfill	***New Mexico:*** NM-B: Use of overburden strata as topsoil substitute growth medium NM-D: Irrigation	***New Mexico:*** NM-D: Annual monitoring to provide data on wildlife use of reclaimed areas NM-E: Computer analysis of mapping and telemetry data to determine effects of mining on wildlife

[a] For the key to case study mines, see appendix A in this volume.

SOURCE: Office of Technology Assessment

2. development of a "scoping" process to determine which baseline and monitoring data actually are needed for permit compliance and reclamation success evaluations;
3. the refinement and validation of analytical techniques for predicting the impacts of mining and for designing reclamation, including better predictive techniques for groundwater quantity and quality impact assessments in cases where there are few field data, and methods for determining the acid-base potential of overburden;
4. the development of methods and criteria for evaluating reclamation success for Phases II and III of bond release; and
5. comparative analyses of the long-term effectiveness of various reclamation methods in different types of mining situations.

In many cases, these research needs cut across disciplines. For example, the ability to delineate and characterize deleterious overburden material clearly affects groundwater quality, but problems with such overburden also would affect the quality of revegetation and, therefore, the land capability.

Although work is ongoing at Western mines that addresses most of these needs, it frequently is limited to site-specific conditions. Without comprehensive comparative analyses of the full range of Western mining environments, research at individual mines will do little to improve the cost-effectiveness of reclamation techniques or to advance the science of reclamation in the West.

The most critical constraint on such research is the lack of available funding. OTA recognizes

the realities of Federal budget cuts in the face of massive deficits, yet other sources of reclamation research funding could be found at the Federal level, in State governments, and in the private sector. These might include, at the Federal level, existing permit fees (which cover the administrative cost of permitting), royalty and bonus payments for Federal coal leases (which go into the general fund), and AML funds (yet to be distributed). It should be noted that the reallocation of these revenues to reclamation research would be controversial.

These same sources of funding are available at the State level, plus the States collect substantial revenues from severance taxes. **Among the State regulatory authorities, however, only North Dakota considers reclamation research within its purview.**

The surface mining industry also should consider investing in cooperative research efforts that would improve the prospects for the long-term success of reclamation and reduce the costs of that reclamation. This is the approach taken by five companies operating on prime farmlands in Illinois (6).

A second constraint is raised by legislation and regulations that impose inflexible design standards that can discourage innovation and do not take into account the tremendous variability among sites. The difficulty and cost of demonstrating alternatives to strict design standards through experimental practices or by obtaining a variance pose a significant obstacle to the extension of these research substitutes to other mining areas, and, in some cases, can unnecessarily increase the cost of reclamation. On the other hand, design standards may be the only available means of ensuring protection of public health and safety in some mining and reclamation situations.

Finally, **the commitment to reclamation in the West that has emerged among coal companies and Federal and State regulatory authorities since 1977 must continue to grow to encompass needed research.** While all parties agree that it is time to "move off of square one" in the implementation of SMCRA, each group tends to downplay the need for continued advancements in baseline and monitoring data, analytical techniques, and reclamation methods because of their potentially high costs. Yet efforts in these areas could result in substantial increases in the quality of, and the likelihood of the long-term success of, reclamation, and could yield significant economic benefits in terms of reduced operating, reclamation, or regulatory costs.

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Chapter 3

Western Surface Mining and Reclamation

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Chapter 3

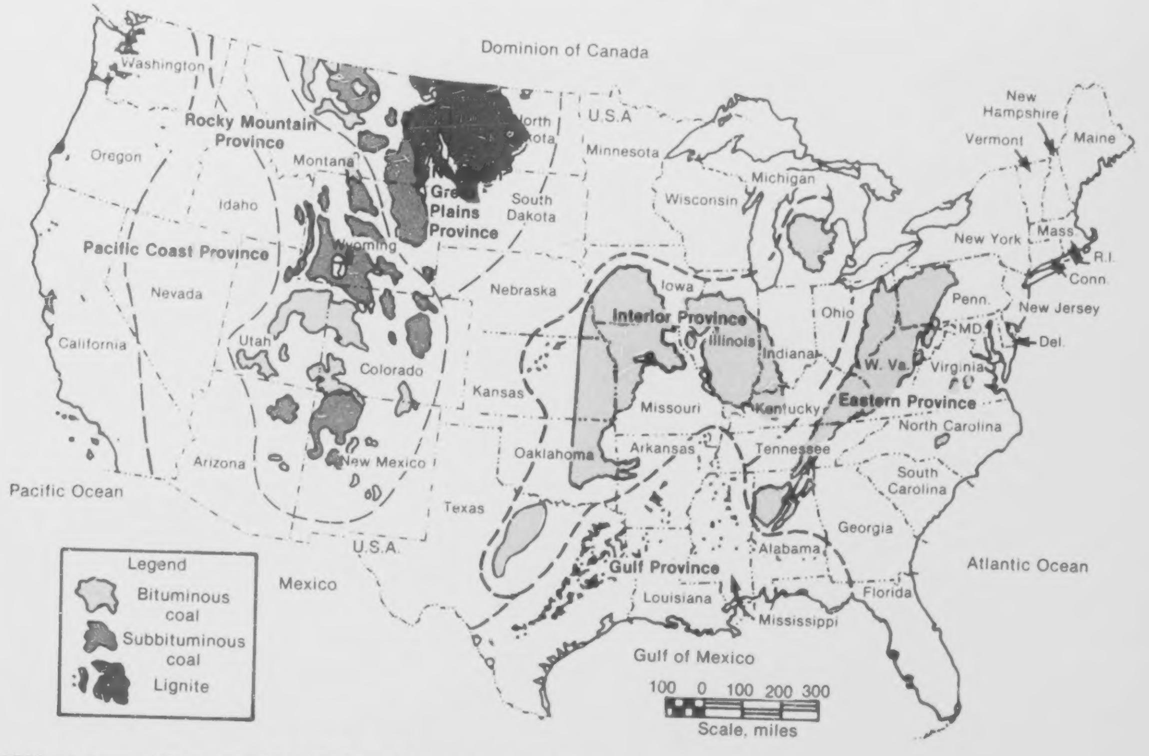
Western Surface Mining and Reclamation

INTRODUCTION

Slightly over half of U.S. coal reserves are located in the Northern Great Plains and Rocky Mountain Coal Provinces of the Western United States (see fig. 3-1) (4). The Federal Government owns between 50 and 60 percent of the coal reserves in the six major Federal coal States (Colorado, Montana, New Mexico, North Dakota, Utah, and Wyoming) (6). In 1983, these States produced 208.9 million tons of coal, or approximately 27 percent of total U.S. production (3). With the exception of mines in Utah and portions of Colorado, most Western coal is produced by surface mining methods (see table 3-1).

The coal-bearing areas in the Western United States are notably distinct from the rest of the country for their relatively small amount of available water, their shallow soils and high erosion rates, and their patterns of land and mineral ownership. Furthermore, within the West, coal mining operations differ greatly from one another due to the diversity of terrain, climate, and land use. The terrain varies from the rolling plains of the Fort Union region of western North Dakota and eastern Montana, to the high rugged mountains of Colorado, to the arid deserts of southwestern Wyoming and northern New Mex-

Figure 3-1.—Generalized Coal Provinces of the United States


Dominion of Canada
Washington
Rocky Mountain Province
Oregon
Montana
Idaho
North Dakota
U.S.A.
Minnesota
Great Plains Province
South Dakota
Pacific Coast Province
Wyoming
Nevada
Nebraska
California
Utah
Colorado
Kansas
Arizona
New Mexico
Oaklahoma
Texas
Pacific Ocean
U.S.A.
Mexico
Legend
Bituminous coal
Subbituminous coal
Lignite
Wisconsin
Michigan
Iowa
Interior Province
Illinois
Indiana
Ohio
Missouri
Kentucky
Arkansas
Tennessee
Gulf Province
Louisiana
Mississippi
Alabama
Georgia
Florida
Gulf of Mexico
100 0 100 200 300
Scale, miles
W. Va.
Eastern Province
Virginia
North Carolina
South Carolina
Penn.
MD.
Del.
New Jersey
New York
Conn.
R.I.
Mass.
Vermont
New Hampshire
Maine
Atlantic Ocean

SOURCE: U.S. Bureau of Mines, adapted from USGS Coal Map of the United States, 1960.

Table 3-1.—1982 Production From Western Coal Mines (thousands of tons)

State	Number of surface mines[a]	Surface production	Percent of total	Number of underground mines[a]	Underground production	Percent of total	Total production
Arizona	2	12,364	100%	0	0	0%	12,364
Colorado	19	11,696	64	30	6,621	36	18,317
Montana	6	27,890	100	0	0	0	27,890
New Mexico	9	19,233	96	3	711	4	19,944
North Dakota	10	17,855	100	0	0	0	17,855
Utah	0	0	0	21	17,029	100	17,029
Wyoming	29	107,085	99	3	1,276	1	108,361
Total	73	196,123	88	57	25,637	12	221,760

[a] Includes some temporarily inactive mines as well as new mines that have not yet reached full production.

SOURCE: Office of Technology Assessment, from 1984 Keystone Coal Industry Manual.

ico. The climate ranges from cold and subhumid in the north, to hot and dry in the San Juan region of New Mexico. Annual precipitation can vary by as much as 50 percent among mines within a region, and by as much as 10 percent even between mines located within 2 or 3 miles of each other (see fig. 3-2).

The nature of the coal resource contributes to the differences among Western surface mines, and between Western mines and those in other parts of the United States. Western coal varies from the lignite of western North Dakota and eastern Montana, with seams from 2 to 50 feet thick, to the bituminous and sub-bituminous coals of Wyoming with seams up to 150 feet thick. Stripping ratios may be as high as 12:1 (cover/coal) or as low as 1:2 (16).

Finally, in the Western United States the Federal Government owns a substantial portion of the surface overlying coal resources as well as the majority of the mineral rights (see table 3-2). As a result, much Western coal must be leased from the Department of the Interior before it can be mined (see ch. 4). In areas where the government owns the coal but not the surface (split estate lands) and where ownership is in a "checkerboard" pattern, coal leasing and development can become complicated.[1]

This chapter describes the environmental and technical context for Western surface mining and reclamation, including the regional ecology and mining and reclamation methods. Chapter 4 outlines the institutional and regulatory context.

THE WESTERN ENVIRONMENT

In general, Western surface mined lands must be reclaimed with less than one-third as much rainfall as mined lands in Appalachia and the Midwest. Droughts are common in the West, and precipitation frequently occurs in short, intense storms with the potential to cause severe erosion. Temperatures fluctuate widely, and high summer daytime temperatures can dry out soil and seeds quickly.

In all the Western coal lands, evaporation exceeds precipitation. The ratio of evapotranspiration to precipitation ranges from 2:1 in the Fort Union region to 6:1 in the San Juan River region. The evaporation rates in the region vary from 48 to 64 inches per year in the northern coal regions, and generally increase to a high of 80 to 96 inches in the southern reaches of the San Juan River region (9). Low rainfall and high evaporation create moisture stress throughout the Federal coal areas.

Furthermore, **organic matter accumulates slowly in arid and semiarid Western soils, and the resulting soil profiles have limited capacity for holding moisture, although the moisture content usually is sufficient to sustain plant growth for 3 months of the year** (9). **In much**

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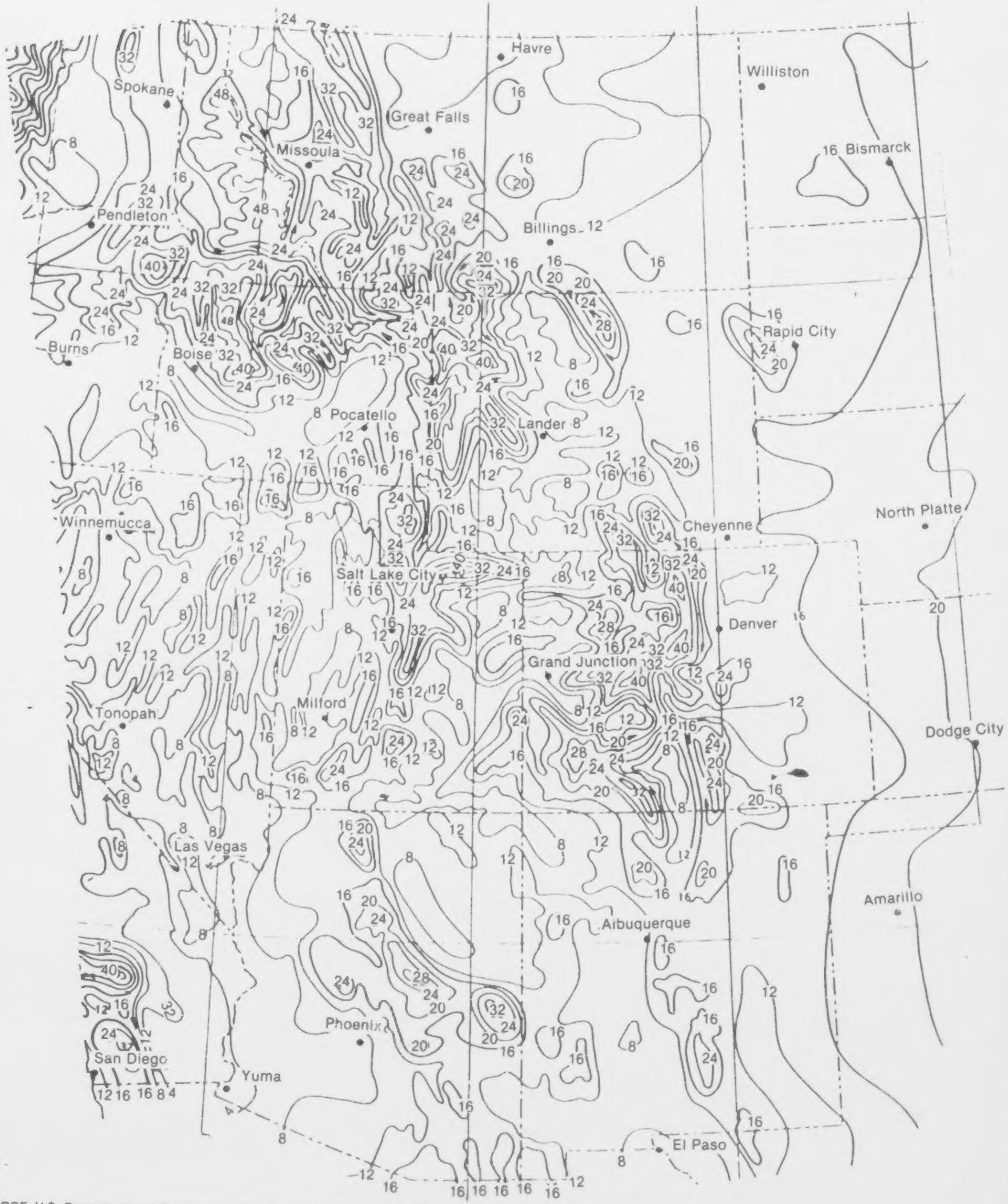
[1] A detailed discussion of leasing in split estate and checkerboard areas may be found in reference 5, pp. 124-129.

Figure 3-2.—Mean Annual Precipitation for the Western Coal Region States


Havre
Williston
Spokane
Great Falls
Missoula
Bismarck
Pendleton
Billings
Rapid City
Burns
Boise
Pocatello
Lander
Winnemucca
Cheyenne
North Platte
Salt Lake City
Denver
Grand Junction
Tonopah
Milford
Dodge City
Las Vegas
Amarillo
Albuquerque
Phoenix
San Diego
Yuma
El Paso

SOURCE: U.S. Department of Commerce, *Climatic Atlas of the United States*, 1968.

Table 3-2.—Ownership of Surface and Coal Resources in Five Western Coal Management Regions[a] (in acres)

Region	Federal surface/ Federal coal[b]	Percent of total	Federal surface/ non-Federal coal[b]	Percent of total	USFS surface/ Federal coal	Percent of total	USFS surface/ non-Federal coal	Percent of total	State surface/ Federal coal	Percent of total
Fort Union:	31,680	1.0%	2,260	—	2,890	—	0	—	14,320	—
North Dakota	800	—[d]	0	—	2,890	—	0	—	3,640	—
Montana	30,880	2.5%	2,260	—	0	—	0	—	10,680	1.0%
Power River:	584,331	9.5%	1,891	—	490,501	7.9%	8,160	—	45,608	1.0%
Montana	193,430	10.3%	60	—	434,515	23.1%	3,120	—	21,190	1.1%
Wyoming	390,901	9.8%	1,831	—	55,986	1.4%	5,040	—	24,418	1.0%
Green River-Hams Fork:	1,179,740	43.9%	4,840	—	2,220	—	640	—	6,012	—
Wyoming	1,124,370	51.8%	960	—	160	—	0	—	2,732	—
Colorado	55,370	10.8%	3,880	1.0%	2,060	—	640	—	3,280	1.0%
Uinta-Southwestern Utah:	765,630	45.5%	6,640	—	384,270	22.9%	1,040	—	4,680	—
Colorado	230,730	40.8%	2,680	—	94,980	16.8%	0	—	0	—
Utah	534,900	47.9%	3,960	—	289,290	25.9%	1,040	—	4,680	—
San Juan River:	1,219,770	48.4%	27,040	1.1%	62,650	2.5%	3,140	—	27,190	1.1%
Colorado	34,470	12.6%	120	—	55,620	20.3%	3,140	—	2,910	1.1%
New Mexico	1,185,300	52.8%	26,920	1.2%	7,040	—	0	—	24,280	1.1%

Table 3-2.—Ownership of Surface and Coal Resources in Five Western Coal Management Regions[a] (in acres)—Continued

Region	State surface/ non-Federal coal	Percent of total	Private surface/ Federal coal	Percent of total	Private surface/ non-Federal coal	Percent of total	Other surface/ Federal coal[c]	Percent of total	Other surface/[c] non-Federal coal	Percent of total	Total coal resource
Fort Union:	111,080	3.0%	1,205,740	32.2%	2,263,470	60.4%	91,580	2.4%	27,450	1.0%	3,750,470
North Dakota	44,600	1.8%	711,160	28.3%	1,643,250	65.4%	79,860	3.2%	26,170	1.0%	2,512,370
Montana	66,480	5.4%	494,580	40.0%	620,220	50.1%	11,720	1.0%	1,280	—	1,238,100
Powder River:	473,099	7.7%	3,814,722	61.7%	720,166	11.6%	70,837	1.2%	32,203	—	6,185,532
Montana	107,980	5.8%	1,046,895	55.8%	443,560	23.6%	2,470	—	2,960	—	1,877,651
Wyoming	365,119	9.2%	2,767,827	69.5%	276,606	6.9%	68,367	1.7%	29,243	—	3,985,338
Green River-Hams Fork:	102,764	3.8%	330,575	12.3%	1,029,655	38.3%	29,648	1.1%	160	—	2,686,254
Wyoming	57,134	2.6%	56,235	2.6%	912,860	42.0%	17,883	1.0%	40	—	2,172,374
Colorado	45,630	8.9%	274,340	53.3%	116,795	22.7%	11,765	2.3%	120	—	513,880
Uinta-Southwestern Utah:	74,590	4.4%	285,410	17.0%	143,290	8.5%	15,320	1.0%	400	—	1,681,270
Colorado	8,190	1.5%	180,070	31.9%	44,360	7.9%	4,160	1.0%	0	—	565,170
Utah	66,400	6.0%	105,340	9.4%	98,930	8.9%	11,160	1.0%	400	—	1,116,100
San Juan River:	160,620	6.4%	273,570	10.9%	183,220	7.3%	430,080	17.1%	133,500	5.3%	2,520,780
Colorado	22,220	8.1%	68,950	25.2%	84,840	31.0%	680	—	1,120	—	274,060
New Mexico	138,400	6.2%	204,620	9.1%	98,380	4.4%	429,400	19.1%	132,380	5.9%	2,246,720

[a] Includes Known Recoverable Coal Resource Areas (KRCRAs) defined as of March 1978.

[b] Includes BLM-administered and other public domain lands, excluding National Forest lands.

[c] Includes Bankhead-Jones acquired lands, Federal withdrawn lands (e.g., military reservations), and Indian lands.

[d] "—" indicates less than 1 percent.

SOURCE: Bureau of Land Management, *Final Environmental Statement Federal Coal Management Program*, 1979.

of the West, rates of natural erosion are among the highest in the country, and soil frequently is lost to flash flooding and hillslope erosion. Vegetative succession also is a slow process in the West due to climatic severity. A disturbed site in the Eastern United States may revegetate itself naturally in 5 to 10 years, but decades or centuries may be needed for natural revegetation in the West (9).

The Fort Union Region[2]

The Fort Union Coal Region in northeastern Montana and western North Dakota (see fig. 3-3) lies in the Missouri Plateau of the Great Plains Coal Province, which extends from the Missouri Coteau westward to the Rocky Mountains. The land consists of rolling prairie and grasslands with isolated coniferous forests and badlands, and occasional buttes and mesas. The region has relatively deep fertile soils formed from glacial till, and the primary land uses are grazing and agriculture, including hay, feed grains, and various types of wheat. In 1983, there were 11 operating surface mines in the North Dakota portion of Fort Union (seven of which incorporate Federal coal), and one in Montana. These mines produced a total of approximately 18.7 million tons of lignite (16). All of the coal is used locally for electricity generation or synthetic fuels production.

The Fort Union region is characterized by a semiarid continental climate, with an average of about 15 inches annual precipitation, most of which occurs in late spring and early summer. Snowfall averages about 33 inches per year. This is a region of climatic extremes, and temperatures

Photo credit: Office of Surface Mining

Due to the relatively harsh climate, soils, and other conditions in the Western coal regions, it may take decades for a disturbed site to revegetate naturally.

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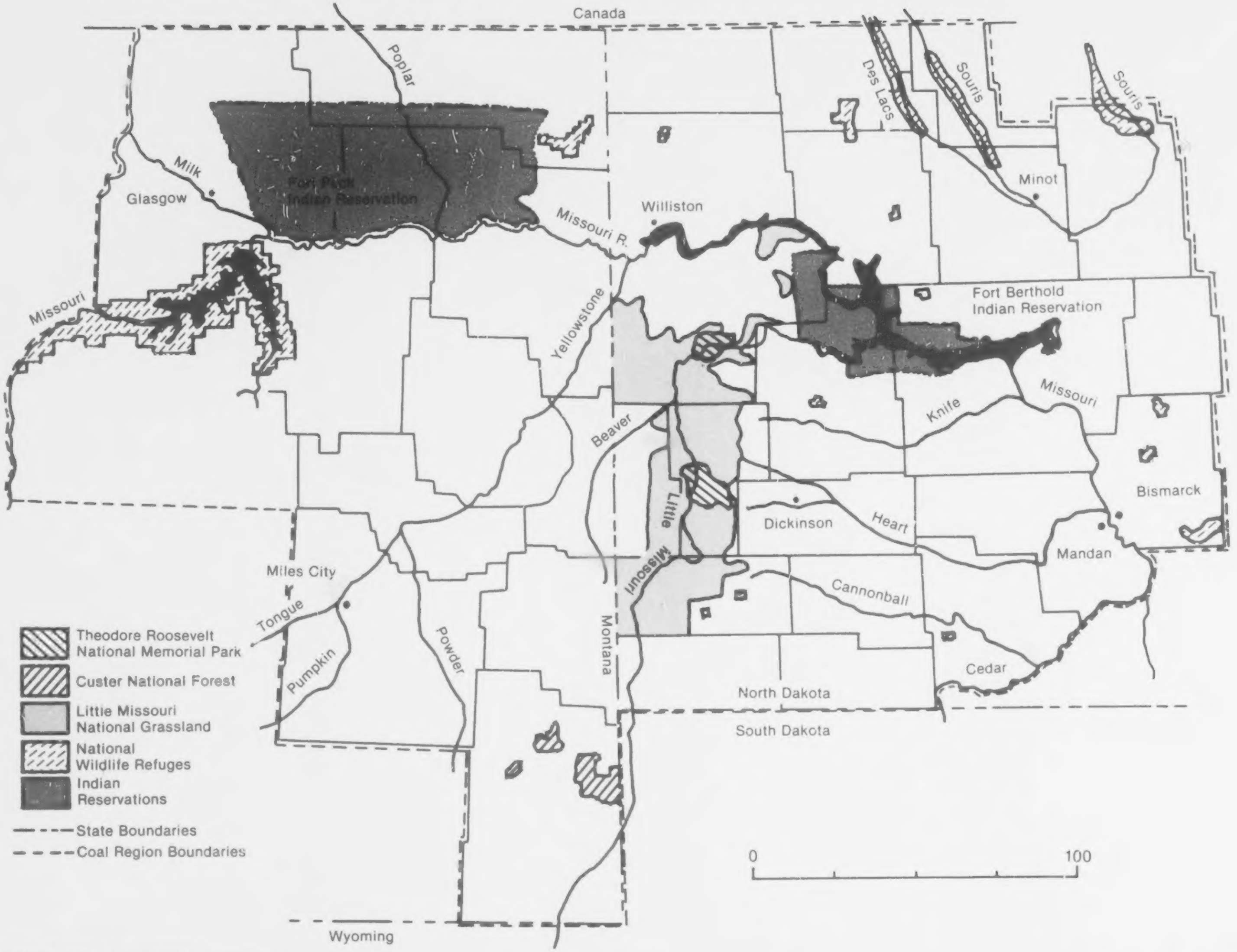
[2] Unless otherwise indicated, the material in this section is adapted from references 9 and 10.

Figure 3-3.—Fort Union Coal Region


Canada
Poplar
Des Lacs
Souris
Souris
Minot
Milk
Glasgow
Fort Peck Indian Reservation
Missouri R.
Williston
Missouri
Fort Berthold Indian Reservation
Yellowstone
Knife
Missouri
Beaver
Little Missouri
Bismarck
Dickinson
Heart
Mandan
Miles City
Cannonball
Tongue
Montana
Pumpkin
Powder
Cedar
North Dakota
South Dakota
Theodore Roosevelt National Memorial Park
Custer National Forest
Little Missouri National Grassland
National Wildlife Refuges
Indian Reservations
State Boundaries
Coal Region Boundaries
0
100
Wyoming

SOURCE: Office of Technology Assessment.

vary widely on an annual, seasonal, and daily basis. The Rocky Mountains modify the prevailing westerly flow of air masses from the North Pacific, but there are no topographical barriers to modify the cold, dry air masses from the polar regions, or the warm, moist air masses from the tropical areas to the south.

Most of the usable surface water in the region occurs in the Yellowstone and Missouri Rivers and the Missouri's reservoir system. Both agriculture and livestock grazing rely heavily on irrigation from these rivers. Surface water also is used for municipal and industrial water supplies. Groundwater is distributed more evenly over the region in deep aquifers, but is not as readily available in as much quantity as surface water. Groundwater is used for domestic, livestock, municipal, and some irrigation water supplies.

Native prairie areas, wetlands (prairie potholes), and woody draws populated with native trees and shrubs are the primary wildlife habitats. The prairie potholes, on the Central Flyway, are part of the primary waterfowl production area of North America.

The Powder River Region[3]

In many respects, the Powder River region (see fig. 3-4) in southeastern Montana and northeastern Wyoming is similar to the adjacent Fort Union region. As with Fort Union, the Powder River region belongs to the Great Plains physiographic province and is part of a broad basin between the Black Hills on the east, the Laramie Mountains to the South, the Bighorn Mountains on the West, and the Cedar Creek anticline in Montana on the North. The region is within the drainage basin for the Missouri River and its tributaries, including the Powder and Yellowstone Rivers.

In 1983, there were 18 active surface mines in the Wyoming portion of the Powder River Coal Region (16 incorporating Federal coal) with 6 under development, and 7 active mines in the Montana portion (6 with Federal coal), and 4 under development. In that year, these mines produced about 121.3 million tons of coal (16). The region also contains valuable oil and gas and uranium deposits, as well as other minerals such as iron and trona.

The topography of the Powder River region varies from relatively steep high open hills with heavily wooded escarpments in the northern part; to gently sloping plains and tablelands in the central area, with badlands breaking the steep slopes adjacent to major drainages; to rolling grass-covered prairie in the southern portion, with conspicuous scoria knobs and erosion escarpments separated and dissected by broad stream valleys. The predominant vegetation types are those typical of rangeland, characterized by low-growing shrubs and herbaceous plants adapted to the semiarid condition of the region. The sagebrush and grassland are broken by patches of coniferous forest (primarily ponderosa pine) in the northern portions of the region, and by deciduous trees (mainly cottonwoods) in riparian areas. As in Fort Union, big game, smaller mammals, raptors, and game birds abound, with the region being part of the Central Flyway for migrating waterfowl.

The area is semiarid with wide annual temperature variations between summer and winter. The region is particularly subject to cold air invasions from the north, although during the winter warm chinook winds blow from the south and west. Maximum precipitation usually occurs in the spring and early summer, with frequent but very light rain showers and occasional heavy cloudbursts that cause flooding. Droughts are common. Even when annual precipitation is higher than average, it may not occur during the critical period of the growing season.

Streams originating in the plains areas tend to be ephemeral (flow only as a result of direct runoff), while streams rising in the Bighorn Mountains and Black Hills usually are perennial, with sustained base flows from groundwater inflow. The numerous stock-water reservoirs and spreader systems on many of the small tributaries result in appreciable depletion of water through evaporation and seepage. The major uses of the surface waters include storage for consumption by livestock, irrigation of hay crops along the base of the Bighorn Mountains and in the North Platte

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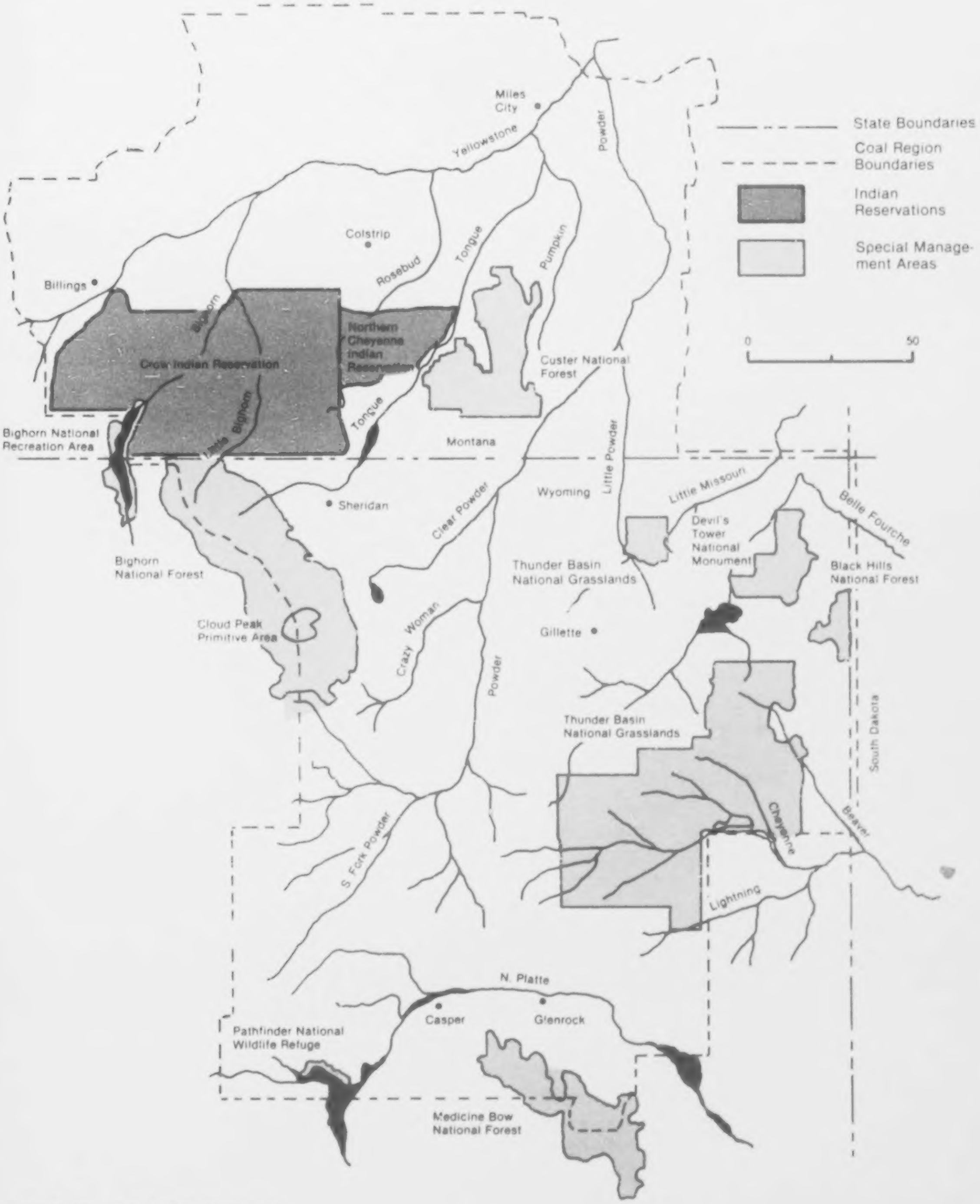
[3] Unless otherwise noted, the material in this section is adapted from references 4, 9, and 11.

Figure 3-4.—Powder River Coal Region


Miles City
Yellowstone
Powder
State Boundaries
Coal Region Boundaries
Indian Reservations
Special Management Areas
0
50
Colstrip
Rosebud
Tongue
Pumpkin
Billings
Bighorn
Northern Cheyenne Indian Reservation
Crow Indian Reservation
Custer National Forest
Little Bighorn
Tongue
Bighorn National Recreation Area
Montana
Little Powder
Little Missouri
Wyoming
Sheridan
Clear Powder
Belle Fourche
Devil's Tower National Monument
Bighorn National Forest
Thunder Basin National Grasslands
Black Hills National Forest
Cloud Peak Primitive Area
Crazy Woman
Gillette
Powder
South Dakota
Thunder Basin National Grasslands
Cheyenne
Beaver
S Fork Powder
Lightning
N. Platte
Casper
Glenrock
Pathfinder National Wildlife Refuge
Medicine Bow National Forest

SOURCE: Office of Technology Assessment.

River drainage, and for municipal water supply systems. Groundwater from shallow aquifers is the principal source of domestic and livestock supplies, and is used extensively for waterflooding in secondary oil recovery. Many of the aquifers have too high dissolved solids or sodium content for use for irrigation or human consumption.

Green River-Hams Fork Region[4]

The Green River-Hams Fork Coal Region is in northern Colorado and southern Wyoming and includes the Green and Yampa River basins, as well as the Hanna basin, Great Divide basin, Red Desert, and portions of the geologically complex Overthrust Belt (see fig. 3-5). In 1983, there were 14 active surface mines (10 with Federal coal) and 2 under development in the Wyoming portion of the region, and 12 active surface operations (6 Federal coal) and 2 under development in the Colorado portion, producing approximately 7 to 8 million tons and 18 million tons, respectively. There also are a number of underground mines in the region. The coals range from sub-bituminous to high volatile bituminous, with seam thicknesses varying from 1 foot to over 30 feet (16).

The Green River-Hams Fork region is topographically diverse, ranging from the low mountain ranges, rolling hills, and broad alluvial valleys of the Yampa coal field; to the sagebrush-covered high plains and rimrock of the Hanna Basin; to the mountains and valleys formed by linear folds and faults in the Overthrust Belt. The predominant vegetation type is sagebrush and associated shrubs such as greasewood and saltbush. Evergreen and aspen forests may be found in the higher elevations, and deciduous trees along the river drainages, with some stretches of open grassland. Livestock grazing is the most extensive land use in the Green River-Hams Fork region, with some cropland (primarily hay) along river bottoms where irrigation water is available.

The region has a semiarid continental climate characterized by dry air, clear skies, little precipitation, high evaporation, and large diurnal temperature changes. Annual precipitation in surface mining areas varies from about 7 inches per year in southwestern Wyoming to around 26 inches in the high plateaus of Colorado. Thunderstorms can occur almost daily in the summer, and blizzards or extremely frigid conditions are not uncommon during the winter months.

The region contains the upper parts of seven river basins and a portion of the Great Divide basin, which has no drainage to either ocean. The North Platte River drains areas east of the Continental Divide, while the Colorado, Green, Little Snake, White, and Yampa Rivers drain west of the divide. Surface water is used for irrigation of cropland, for livestock and wildlife, and to meet industrial and municipal demands. Groundwater may be found at varying depths throughout the area, and many of the coal beds are potential aquifers. The predominant uses of groundwater are for livestock and ranch wells, with some wells supplying oil drilling operations.

In general, the Green River-Hams Fork region provides excellent habitat for big game animals, which summer in the aspen and conifer habitats of the higher elevations and winter at lower elevations in mountain shrub and sagebrush areas. In some areas, winter density of elk is 50 per square mile. Game birds, especially grouse, are common, as are eagles and other raptors. Wild horses also may be seen throughout the region.

The San Juan River Region[5]

The San Juan River Coal Region is in the Colorado plateau, encompassing northwestern New Mexico and part of southwestern Colorado, including the Four Corners area (see fig. 3-6). It is essentially a high plateau, with low mesas, buttes, and badlands, occasionally cut by deep canyons formed by streams. The basin is surrounded by mountain ranges: the San Juans to the north, San Pedro Mountain and the Naciementos to the east, the Zunis on the south, and the Chuska Mountains to the west, with altitudes ranging from 5,000 to 7,500 feet. The Federal Government owns or manages much of the surface, including National Forest, Bureau of Land Management,

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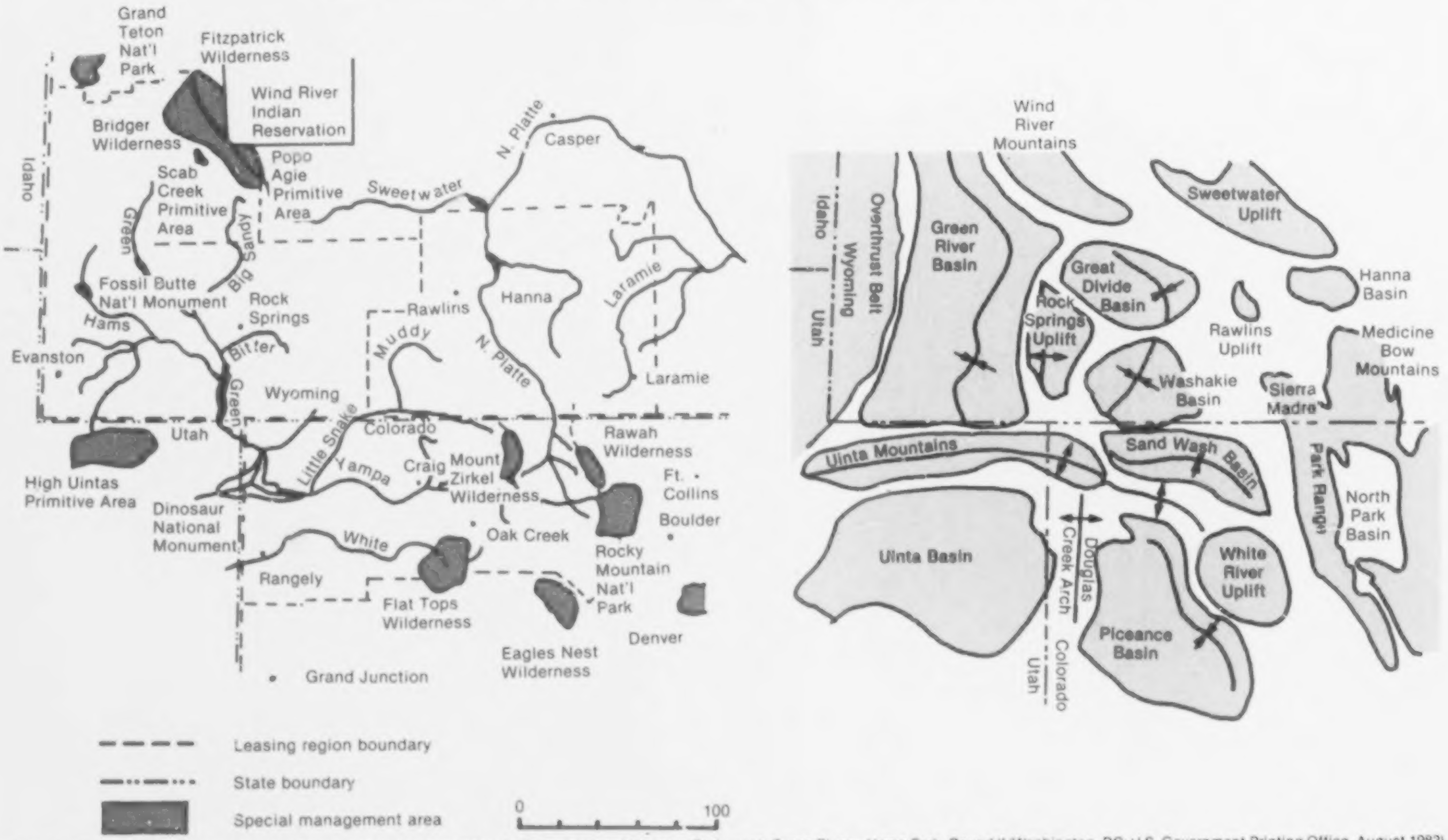
[4] Unless otherwise indicated, the material in this section is adapted from references 8 and 9.

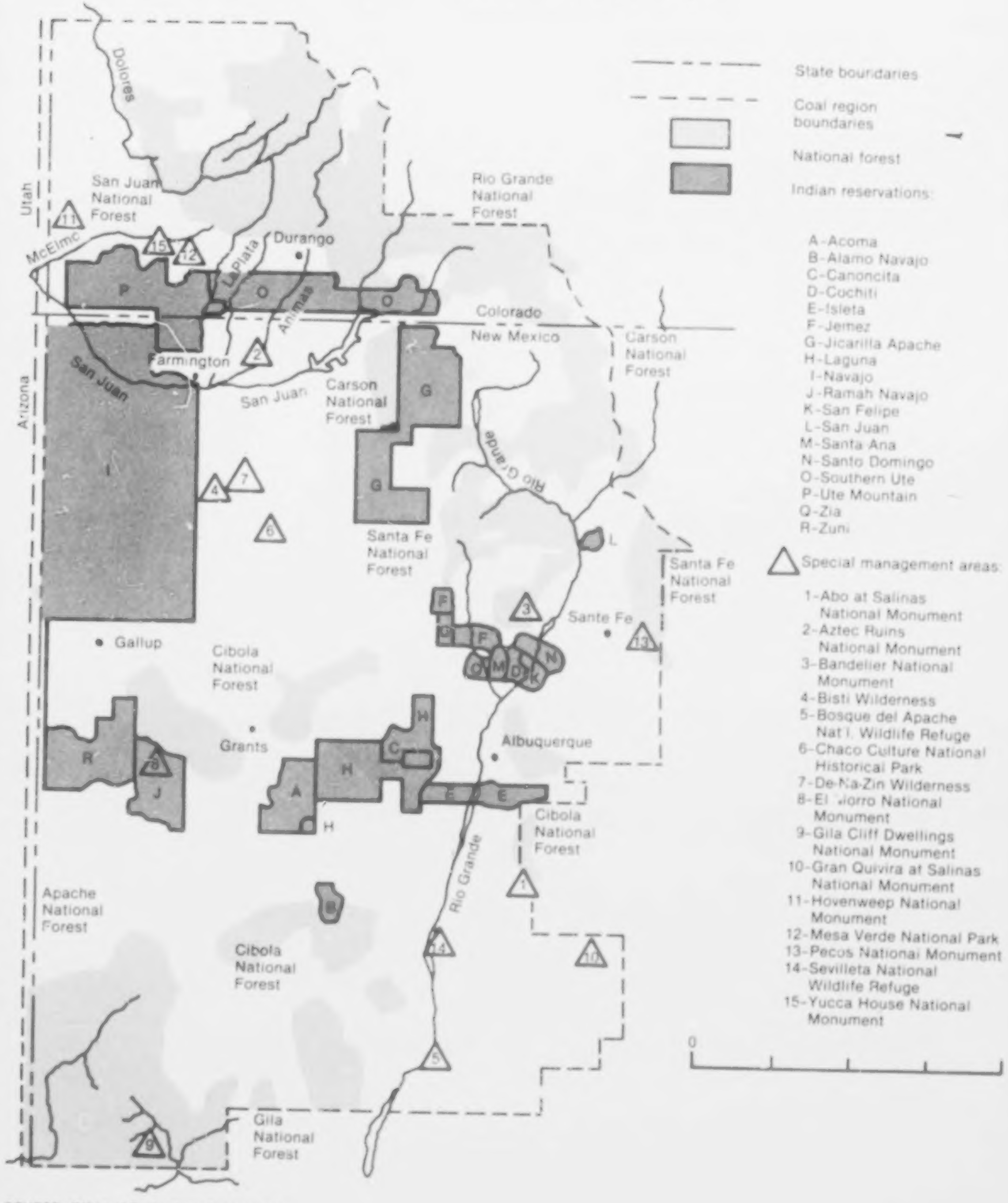
[5] Unless otherwise noted, the material in this section is adapted from references 4, 7, and 9.

Figure 3-5.—General and Tectonic Maps of Green River-Hams Fork Coal Region


Grand Teton Nat'l Park
Fitzpatrick Wilderness
Wind River Indian Reservation
Bridger Wilderness
Popo Agie Primitive Area
Scab Creek Primitive Area
Idaho
Green
Big Sandy
Sweetwater
N. Platte
Casper
Fossil Butte Nat'l Monument
Rock Springs
Rawlins
Hanna
Laramie
Hams
Evanston
Bitter
Muddy
N. Platte
Laramie
Wyoming
Green
Utah
Colorado
Little Snake
Yampa
Craig
Mount Zirkel Wilderness
Rawah Wilderness
Ft. Collins
Boulder
High Uintas Primitive Area
Dinosaur National Monument
White
Oak Creek
Rocky Mountain Nat'l Park
Rangely
Flat Tops Wilderness
Denver
Eagles Nest Wilderness
Grand Junction
Leasing region boundary
State boundary
Special management area
0
100
Wind River Mountains
Idaho
Wyoming
Utah
Overthrust Belt
Green River Basin
Rock Springs Uplift
Great Divide Basin
Sweetwater Uplift
Hanna Basin
Rawlins Uplift
Medicine Bow Mountains
Washakie Basin
Sierra Madre
Uinta Mountains
Sand Wash Basin
Park Range
North Park Basin
Uinta Basin
Douglas Creek Arch
White River Uplift
Piceance Basin
Utah
Colorado

SOURCE: U.S. Department of the Interior, Bureau of Land Management, *Draft Environmental Impact Statement, Green River—Hams Fork, Round II* (Washington, DC: U.S. Government Printing Office, August 1983).

Figure 3-6.—San Juan River Coal Region


State boundaries
Coal region boundaries
National forest
Indian reservations:
A-Acoma
B-Alamo Navajo
C-Canoncita
D-Cochiti
E-Isleta
F-Jemez
G-Jicarilla Apache
H-Laguna
I-Navajo
J-Ramah Navajo
K-San Felipe
L-San Juan
M-Santa Ana
N-Santo Domingo
O-Southern Ute
P-Ute Mountain
Q-Zia
R-Zuni
Special management areas:
1-Abo at Salinas National Monument
2-Aztec Ruins National Monument
3-Bandelier National Monument
4-Bisti Wilderness
5-Bosque del Apache Nat'l. Wildlife Refuge
6-Chaco Culture National Historical Park
7-De-Na-Zin Wilderness
8-El Morro National Monument
9-Gila Cliff Dwellings National Monument
10-Gran Quivira at Salinas National Monument
11-Hovenweep National Monument
12-Mesa Verde National Park
13-Pecos National Monument
14-Sevilleta National Wildlife Refuge
15-Yucca House National Monument
0
Dolores
Utah
San Juan National Forest
McElmo
Durango
LaPlata
Animas
Rio Grande National Forest
Colorado
New Mexico
Carson National Forest
Farmington
San Juan
San Juan
Arizona
Carson National Forest
Rio Grande
Santa Fe National Forest
Santa Fe National Forest
Sante Fe
Gallup
Cibola National Forest
Grants
Albuquerque
Cibola National Forest
Rio Grande
Apache National Forest
Cibola National Forest
Gila National Forest

SOURCE: Office of Technology Assessment

and Tribal lands. In 1983, there were 10 active surface mines in the New Mexico portion of the region (5 incorporating Federal coal, including Tribal coal), with 4 under development. The Colorado portion of the region has one active surface mine with Federal coal and four with private coal. The region's surface mines produced approximately 20.3 million tons of coal in 1983 (16).

The region lies south of the major storm belt from the Pacific across the Rockies, and has a semiarid to arid climate. Annual precipitation averages less than 10 inches, although the higher elevations may receive as much as 20 inches due to greater snowfall. Summer rainfall is primarily from intense local thunderstorms that frequently cause flash flooding. Daily high-low temperatures show a large variation, and potential evaporation exceeds normal precipitation by a factor of 6 or more.

The San Juan is the major river draining the region. Surface waters in the region generally have high concentrations of suspended sediment, especially during the floods associated with spring snowmelt and summer thunderstorms. The primary use of surface water is for irrigation. Groundwater generally is of good quality where it is available, and is used for livestock and domestic consumption, as well as in support of coal and uranium mining. The heaviest groundwater pumping occurs around Gallup, New Mexico, where withdrawals for coal and uranium mining and for municipal use exceed the natural replacement to the aquifers.

The principal vegetation types include grassland and grassland-shrub at the lower elevations, pinon-juniper up to 7,000 feet, and conifer forest above 7,000 feet. Livestock, dryland farming (primarily in Colorado), and irrigated farming along water courses are important land uses, along with energy development (coal, oil and gas, uranium). Many of the grassland-shrub areas in the region have been severely overgrazed by livestock.

WESTERN SURFACE MINING TECHNIQUES

Surface mining is the oldest and least expensive method of mining coal in the United States and currently is used to obtain about half of total U.S. coal production. Due to the nature of the Western coal resource, which has a relatively low Btu value and generally is near the surface, surface mining is the predominant method in that part of the United States, accounting for around 80 percent of regional production (see table 3-1). The techniques now practiced in Western surface mining operations have been developed to maximize recovery of the coal (which often occurs in multiple seams) with machinery that ranges from simple tractors equipped with backhoes, to very large electric shovels and draglines.

In general, surface mining involves exposure of the coal seam by removal of the overlying soil and rock material (overburden). The overburden is stored in spoil piles until needed to backfill the pit after the coal has been extracted. **Due to the size of Western surface mining operations, where mines producing 5 to 10 million tons per year are typical, and mines producing 10 to 20 million tons per year are not uncommon, the scale of the equipment is correspondingly larger than that in the East and Midwest.** Shovel and dragline bucket capacities range from 40 to 115 cubic yards, and haul trucks have gross weights up to 220 tons. The larger scale of mining and operational considerations resulting from the topography and other factors also necessitate the use of mining methods different from those in the East.

***Area or open-pit mining* is the method most commonly used to extract Western coal.** Large open pits are developed to expose the coal, using a variety of equipment. The pit advances as coal is extracted, and the mined-out portions are backfilled. The size and shape of the pits, and the way in which the overburden is stored temporarily ("spoiled") and the pit backfilled, are a function

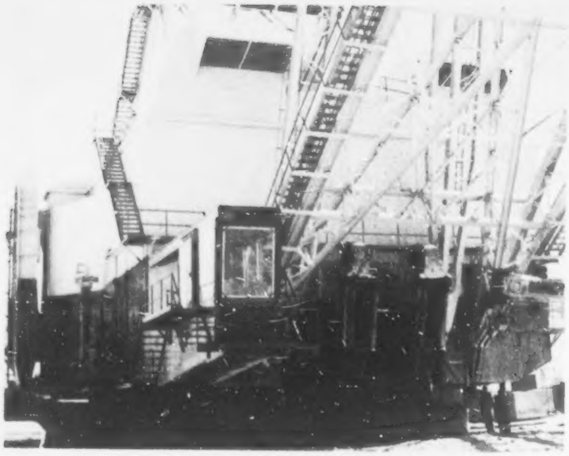


Photo credit: Jenifer Robison, OTA staff

Due to the large size of Western surface coal mines, where annual production may be as high as 15 to 20 million tons per year, the scale of the equipment is correspondingly larger than that used in the East and Midwest.

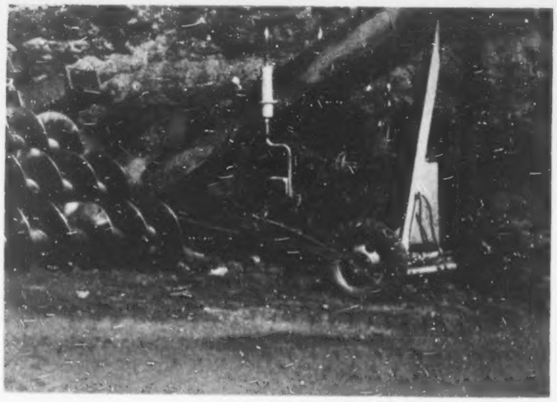


Photo credit: Jenifer Robison, OTA staff

Auger mining is used in some Western coal areas to recover additional coal when the overburden becomes too thick for exposure of the entire seam to be economical.

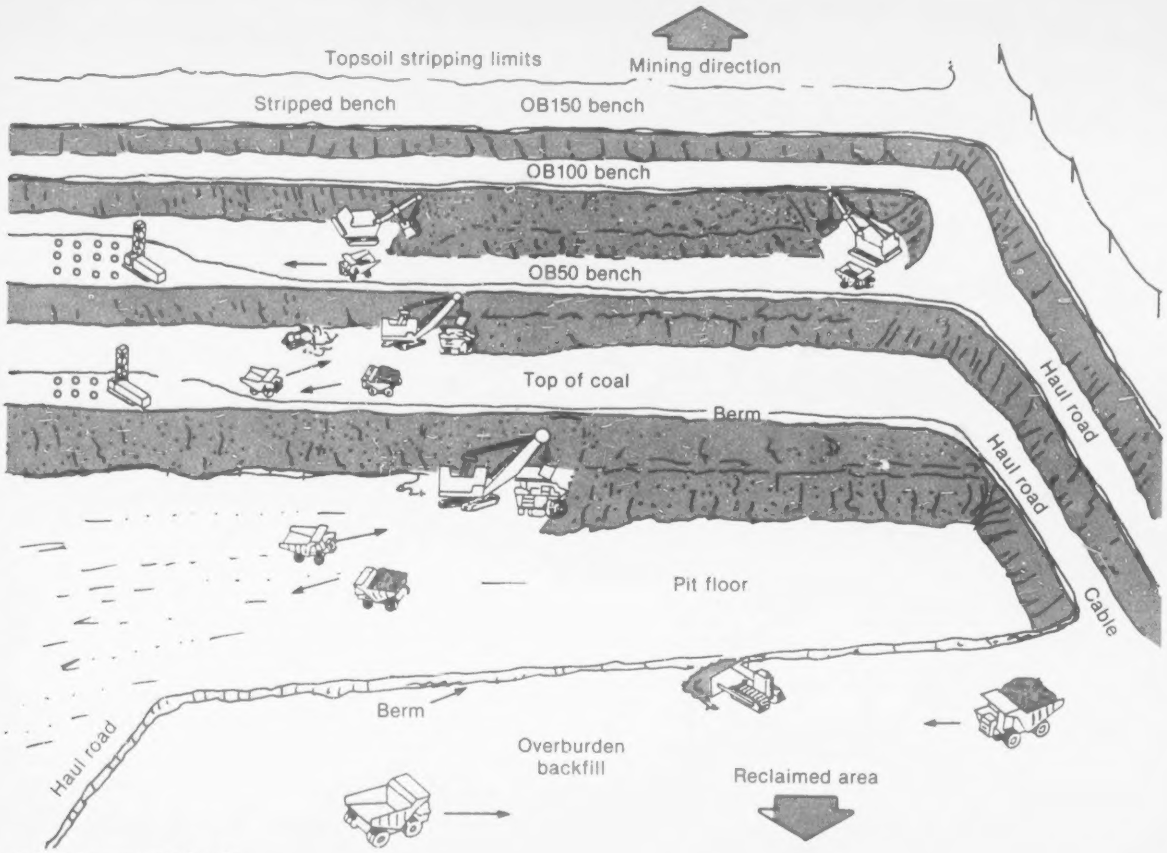
of the attitude, thickness, and number of the coal seams, and of the equipment selected (see fig. 3-7). Longer dragline booms and the development of multiple-bench operations enable Western mines to reach coal buried under overburden 200 feet thick or more, and methods have been proposed for mining to stripping depths of over 500 feet (see fig. 3-8).

In contrast, common Eastern mining methodologies include contour and auger mining. ***Contour mining*** is used in hilly areas, as in much of Appalachia, where a coal seam outcrops on the side of a hill. The mine begins at the outcrop and proceeds along the contour of the bed in the hillside, until the ratio of overburden to coal becomes too great for surface mining to be feasible. At that point ***auger mining*** where huge drills are driven horizontally up to 200 feet into the coal seam, is used to recover additional coal (see fig. 3-9). These mining methods are not useful on the broad, flat plains that overlie most Western coal. They are, however, used to a limited extent at some of the small mines in hilly terrain in Colorado and New Mexico, and to recover some of the steeply dipping coal in Wyoming.

SURFACE MINE IMPACTS AND RECLAMATION

Surface mine reclamation may proceed in parallel with or independently of excavation. With parallel reclamation, the overburden from an active area is placed in the area of the previous cut, and then backfilled, graded, and compacted (if necessary). At the same time, topsoil is hauled from a newly disturbed area and applied directly to the recontoured overburden without stockpiling. This method avoids expensive double handling of the overburden, and is the general practice (after the initial cut) at larger Western operations. Where parallel reclamation is not feasible, the topsoil from an active area is stockpiled and the overburden accumulated in spoil piles until these materials are needed to fill a mined-out pit. At that time, the overburden is backfilled and graded to postmining contour, and then the topsoil is hauled to the recontoured area, graded, and prepared for seeding and planting. **While Western surface mine reclamation can be rela-**

Figure 3-7.—Area or Open-Pit Mining


Topsoil stripping limits
Mining direction
Stripped bench
OB150 bench
OB100 bench
OB50 bench
Top of coal
Berm
Haul road
Haul road
Cable
Pit floor
Berm
Haul road
Overburden backfill
Reclaimed area

SOURCE: Thunder Basin Coal Co.

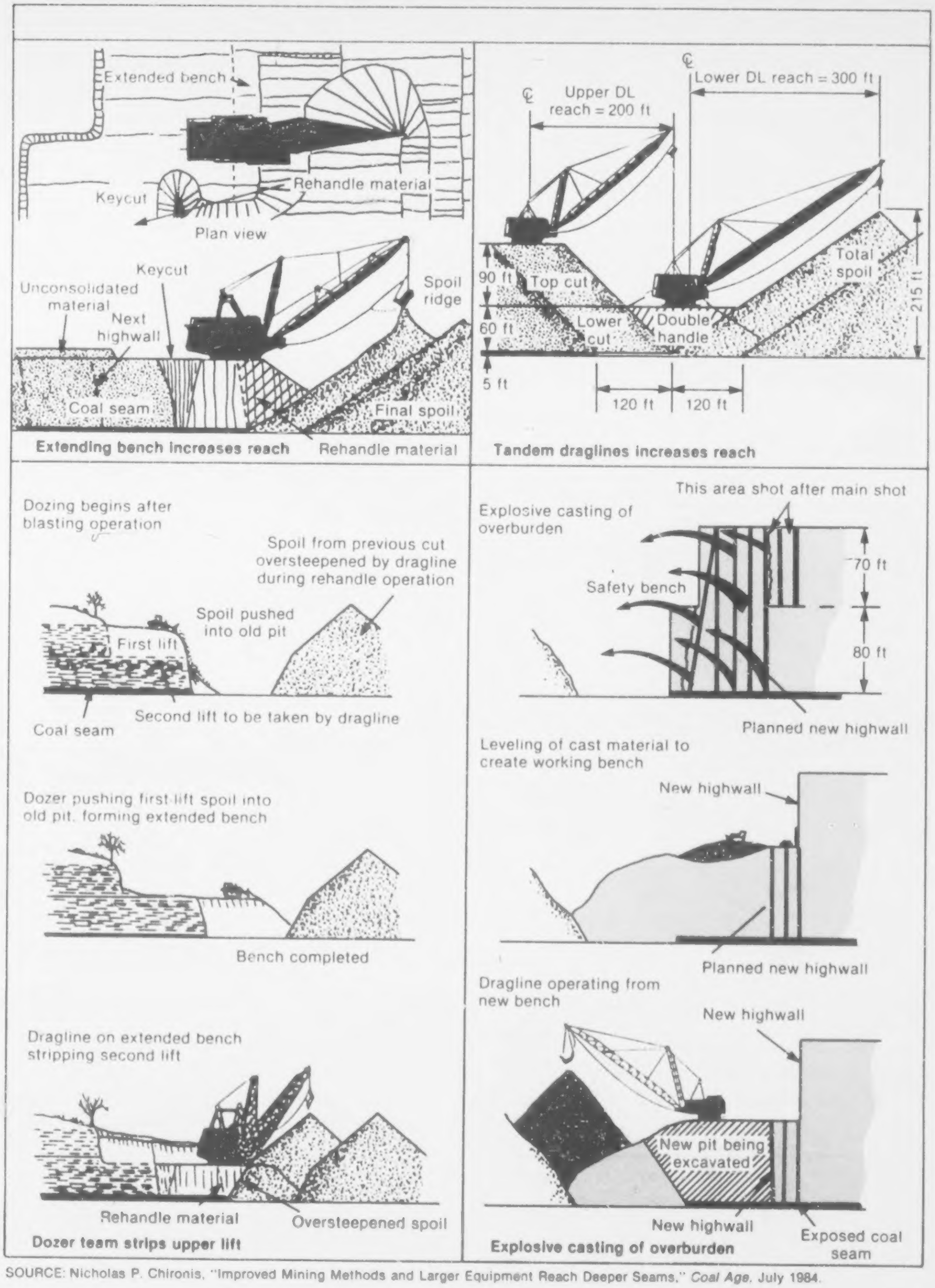
tively straightforward, the wide range of hydrologic, soils, vegetation and other conditions that may be encountered, and the extensive regulatory requirements imposed under Federal and State reclamation laws, also can make it an extremely complicated process.

This section reviews the reclamation methods or techniques currently in use at mines in the Western United States. Special reclamation situations are illustrated with examples, highlighted in boxes, from Western mines whose permit applications were reviewed for this assessment. The permitting process and the data and analyses used to develop a mining and reclamation plan are discussed in detail in chapters 4 through 6. Subsequent chapters address the the criteria and analytical techniques used to evaluate the success of reclamation, special reclamation tech-

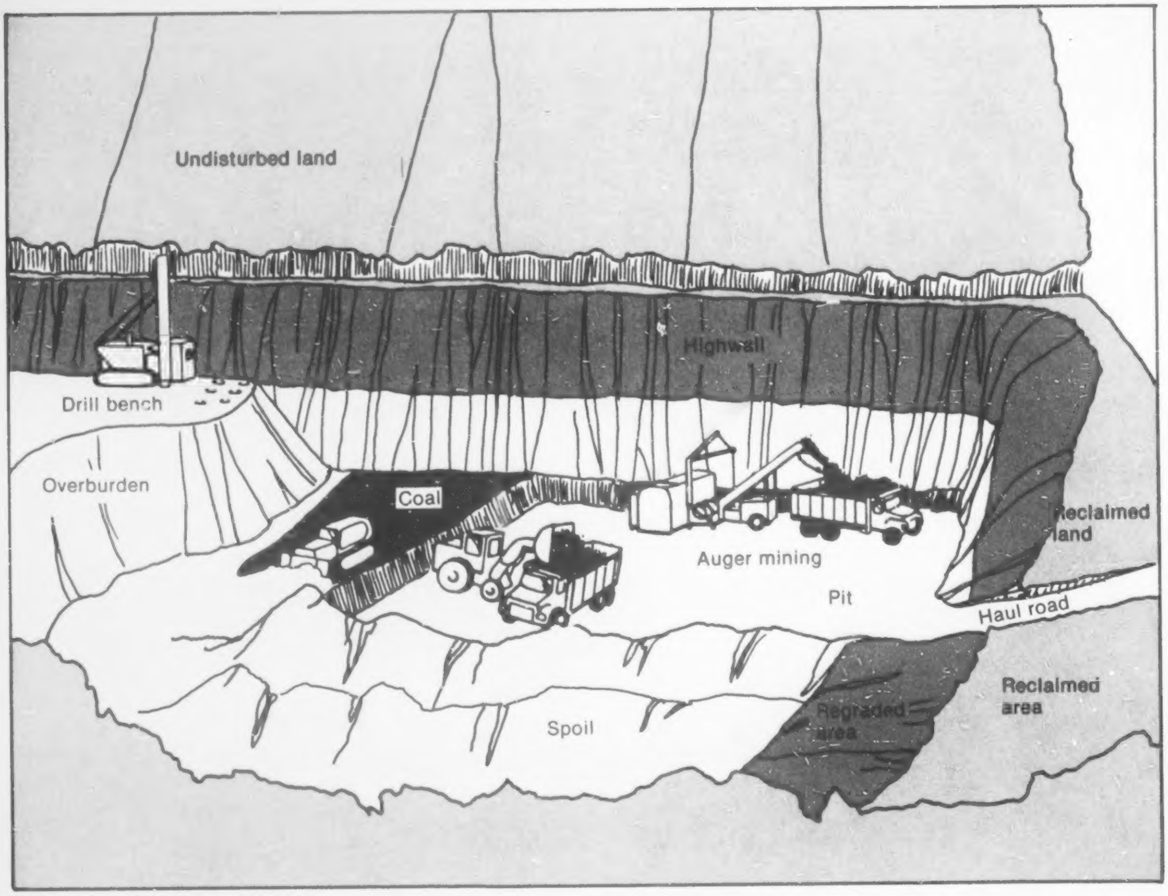
Photo credit: Utah International Inc.

The progress of mining and reclamation: 1) active mine pit moving toward the right, with spoil piled in already mined out areas (center); 2) recently regraded area being prepared for reclamation (foreground); 3) recently revegetated area under irrigation (center and left); 4) undisturbed sodic badlands (background).

Figure 3-8.—How To Help Draglines Reach Deeper Seams


Extended bench
Keycut
Rehandle material
Plan view
Keycut
Unconsolidated material
Next highwall
Spoil ridge
Coal seam
Final spoil
Extending bench increases reach
Rehandle material
Upper DL reach = 200 ft
Lower DL reach = 300 ft
90 ft
Top cut
60 ft
Lower cut
Double handle
Total spoil
215 ft
5 ft
120 ft
120 ft
Tandem draglines increases reach
Dozing begins after blasting operation
Spoil from previous cut oversteepened by dragline during rehandle operation
Spoil pushed into old pit
First lift
Coal seam
Second lift to be taken by dragline
Dozer pushing first-lift spoil into old pit, forming extended bench
Bench completed
Dragline on extended bench stripping second lift
Rehandle material
Oversteepened spoil
Dozer team strips upper lift
Explosive casting of overburden
This area shot after main shot
70 ft
Safety bench
80 ft
Planned new highwall
Leveling of cast material to create working bench
New highwall
Planned new highwall
Dragline operating from new bench
New highwall
New pit being excavated
New highwall
Exposed coal seam
Explosive casting of overburden

SOURCE: Nicholas P. Chironis, "Improved Mining Methods and Larger Equipment Reach Deeper Seams," *Coal Age*, July 1984.



SOURCE: Office of Technology Assessment

niques and issues, and technological innovation and research in reclamation methods.

Soil and Overburden[6]

The methods used to salvage and redress topsoil and to handle overburden vary widely among mines, depending on the physical and chemical characteristics of the soil/overburden and the configuration of the mine. For soil handling, a system is developed for each mine, using the baseline soil inventory in the permit application as a guide, in order to salvage the right amount of topsoil from the appropriate areas (see chs. 5 and 6 for further discussion of soil inventories and salvage plans). The topsoil usually is salvaged with large machines called scrapers, but deep soils may be salvaged with truck and shovel equipment. Similarly, each mine will handle overburden differently, depending on its physical and chemical characteristics. After the overburden is drilled and blasted, it is removed either with a dragline or electric shovel and truck.

Characterization

Soil is ranked as suitable or unsuitable for salvage according to chemical or physical criteria that affect revegetation success. These criteria are established by the State regulatory authority and reflect characteristics of climate, vegetation, and geology of the mining regions in that State (see ch. 6, table 6-4). These criteria, methods of data collection, and suitability determination are discussed in chapters 5 and 6. All suitable materials normally are salvaged for use in reclamation (unless the suitable soil is very deep), and unsuitable materials are spoiled with the overburden (see "Overburden Handling," below). As discussed in chapter 8, salvaging very deep soils without special handling (e.g., two lifts; see below) and without regard to the biological viability of the soil can make revegetation more difficult. If sufficient topsoil is not available, a suitable topsoil layer must be reconstructed from overburden or interburden materials (see examples from Western mining situations illustrated in boxes 3-A and 3-B).

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[6] Unless otherwise noted, the material in this section is adapted from reference 12.

Overburden also is ranked as suitable or unsuitable, the goal being to ensure that overburden material in contact with redressed soil and within the root zone will not be deleterious to soil development and plant growth. The delineation of deleterious overburden is governed by criteria (shown in table 6-3) often referred to as "suspect levels." Overburden material that tests above those levels is considered potentially "toxic" (defined as "chemically or physically detrimental to biota" in the Federal regulations) and must be specially handled to protect groundwater and/or covered with sufficient benign material to protect vegetation (see box 3-B). The methods for identifying and handling unsuitable and toxic materials are discussed in chapters 6 and 8.

Overburden Handling

The overburden on a site usually has both deleterious and benign zones, although the overburden on some sites may be all benign or even all deleterious. If all of the overburden is benign, the spoil can be backfilled without special handling. Where some or all of the overburden has deleterious qualities, the mine plan must ensure that revegetation and postmining surface and groundwater quality will not be adversely affected (see box 3-H, below). This requirement often is satisfied with a permit stipulation that the top 4 to 8 feet of the recontoured spoil must be tested for unsuitable characteristics prior to replacement of the topsoil. Otherwise, the unsuitable material must be rehandled and buried in the pit or spoil piles (see box 3-C), covered with suitable spoil (usually 4 feet or more in thickness) from an adjacent area, or treated (e.g., liming acid spoil).

Special handling of overburden can be accomplished much more easily in a truck and shovel

Box 3-A.—Use of Overburden as a Topsoil Substitute[1]

The regulations in all five of the study-area States allow the use of supplemental overburden material in addition to, or in place of, existing topsoils when the supplemental material can be shown to be as good or better than the existing topsoil. Although such a situation is extremely rare, at one mine the premining soils inventory showed most of the site to consist of badlands or shale barrens, and all of the surface materials were determined to be unsuitable for use as topsoil in reclamation. A sandstone stratum (clayey sandstones or siltstones with sodium adsorption ratios—SARs—of 32 to 38) over 10 feet thick in the overburden was proposed for use as an alternative topdressing material. The material is stockpiled separately from the remainder of the overburden, and redressed like topsoil. Salvage operations try to maximize the use of the coarser textured materials with clay contents less than about 25 to 30 percent. A permit stipulation requires the material to be redressed in two lifts to a total depth of 14 to 18 inches; in practice, each lift has a depth of 8 to 10 inches, resulting in a total depth of 16 to 20 inches. The first lift will be disked into the underlying spoil to minimize formation of a textural barrier. The operator has established a research plot to evaluate use of the sandstone as an alternative topdressing material. Several different treatments of soil thickness (0 to 18 inches), number of lifts, erodibility, and disking are being investigated, as well as the effects of the high sodium content on the physical characteristics of the spoil.

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[1] See case study mine M in reference 12.

Box 3-B.—Obtaining Sufficient Topdressing for Unsuitable Overburden[1]

Overburden characterization at a mine in New Mexico indicated that essentially all of the overburden is deleterious due to high SAR and clay content. The Federal regulations require "appropriate depth of cover" over toxic materials, but at the time of permitting, the State program did not have a definition of "toxic." The operator contended that non-saline, sodic spoils (materials with high sodium relative to calcium and magnesuim, but low total sodium and other salts) are not toxic to adapted species. During permitting, the operator argued that 4 feet of cover are not available onsite, that native species are adapted to the conditions, and that sodification of the topdressing was not a concern. Subsequent research conducted by the operator supported the latter contention, but it was challenged by the regulatory authority, which imposed a permit stipulation that required a soil monitoring plan. To enable the operator to obtain additional volumes of cover, the regulatory authority relaxed the suitability criteria, based on the natural soil chemistry, to allow use of saltier, more sodic materials. Based on the relaxed criteria, subsequent volume calculations showed 11.2 inches of topdressing to be available. The regulatory authority contended that 11.2 inches would be insufficient due to the high SAR, and required 18 inches. A regolith (weathered bedrock) study also was required by the regulatory authority to delineate additional suitable material. The study found two isolated bodies of regolith that could provide about 6 inches more cover, for a total of almost 18 inches. Over most of the mined area, topsoil and subsoil will be redressed to a depth of 18 inches in two lifts of 4 inches and 14 inches, respectively. In areas of benign spoil, two 4-inch lifts will redress topsoil to a depth of 8 inches.

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[1] See case study mine L in reference 12.

Box 3-C.—Special Handling of Unsuitable Material[1]

A dragline operation in the eastern Powder River basin is mining two seams with a gray shale interburden that has a high clay content. When the mine was first permitted under a pre-SMCRA State law, high clay contents were considered unsuitable, and the regulatory authority did not allow the interburden to be spoiled in such a manner as to be found on the surface of the regraded spoil. This required very expensive double handling of the spoil in order to make room deep in the overburden spoil for the interburden. In the early 1970s, research on copper:molybdenum ratios in yellow and white sweet clover (molybdenum accumulators) growing on the site showed ratios (i.e., high molybdenum relative to copper) suspected to be capable of causing molybdenosis in cattle. Subsequent sampling of the overburden and spoil at this mine showed molybdenum concentrations still above suspect levels, and the requirement for double handling was retained when the mine was permitted under the permanent regulatory program. Permit stipulations required recontoured spoil sampling and a special study of the molybdenum problem. That study, conducted from 1979 to 1982, found that "segregation of the interburden material did not have a statistically significant effect on the molybdenum content or copper:molybdenum ratios of the seeded plant species, when compared to vegetation grown on the mixed interburden area." As a result of this and other findings, the company requested that the requirement to bury the interburden be eliminated. Based on the regulatory authority's understanding that the interburden would be buried to a considerable degree over much of the remaining area to be mined, on the condition that the company submit a regraded spoil/vegetation sampling and analysis program, and on the condition that problem spoil materials detected in that program would be removed and/or buried, the regulatory authority granted the request in 1984. If spoil samples indicate unsuitable pH, salinity, or SAR, the area would be rehandled. If molybdenum is high (above 6 ppm), the spoil will be rehandled or covered; if it is above the suspect level (between 2 and 6 ppm), vegetation transects will be monitored on the revegetated surface. If molybdenum levels in the forage become a problem for grazing animals, the affected area will have to be completely reconstructed.

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[1] See case study mine C in reference 10.

operation than with a dragline. The top bench (40 to 50 feet), which is less likely to have deleterious qualities because it is at least partially weathered, usually is placed on top of the spoil during recontouring in a truck and shovel operation. With a dragline, however, overburden material closer to the bottom of the stripping depth is more likely to end up on top of the recontoured spoil where it will be subject to oxidation. An inefficient modified dragline swing that increases the likelihood of undesirable material being buried, or expensive double handling may be required to prevent this occurring. With either type of equipment, the situation can become more complex if strata exhibit parameters that are deleterious both to revegetation and to groundwater quality (e.g., selenium), or exhibit multiple deleterious parameters (e.g., overburden exhibiting both a high SAR and high nitrates; see "Groundwater," below).

Under SMCRA and the State programs, the overburden must be backfilled and graded to the approximate original (premining) contour unless specifically exempted due to excess or thin overburden. The design of the recontoured surface must have slopes that will provide a stable postmining landscape that is subject to neither excessive erosion nor deposition, and is compatible with the postmining land use. As discussed in chapter 8, however, recontouring to the approximate original contour may be impossible in some instances (e.g., removal of bedrock outcrops).

Photo credit: Office of Surface Mining

Special handling of potentially deleterious overburden material can be accomplished more easily with a shovel, because the benign upper bench is more likely to be spoiled on top during backfilling and recontouring.

Photo credit: Jenifer Robison, OTA staff

With a dragline, overburden material closer to the bottom of the stripping depth is more likely to end up on top of the recontoured spoil, where it will be subject to oxidation, enhancing its potential for deleterious effects on revegetation.

Some subsidence has occurred on recontoured surfaces in Colorado, Montana, North Dakota, and Wyoming. For example, at one mine in Montana, a depression about 4 feet deep, 50 feet wide, and 200 feet long has formed; a long area parallel to dragline spoils has subsided leaving a 1-foot high scarp; and a few cracks several hundred feet long have appeared. Over the long term, there is a potential for subsidence in dragline operations, where the mine floor becomes covered with thin strata of coarse rubble composed of wasted coal and boulders that collect at the bottoms of spoil ridges. These rubble zones can become confined aquifers postmining, and there is a possibility that, over the long term, the rubble will break down in the water, leaving a void that could cause subsidence (14).

After final grading, the recontoured spoil is prepared for topsoiling, typically by ripping with a chisel plow to alleviate compaction, prevent a spoil/soil barrier from forming, and prevent the soil from slipping on the spoil surface.

Soil Handling

Salvaged soil may be stockpiled until it is needed for reclamation, or it may be hauled directly to an area being reclaimed, depending on the timing of the mining and reclamation. Rehandling stockpiled topsoil is expensive, and the combined haul distance from salvage to stockpile and then to reclamation area may be farther than directly from salvage area to reclamation area. Moreover, **soils that have been stockpiled for more than about 2 years deteriorate biologically due to decreases in the viability of seeds, roots, and microbiota, increasing the difficulty of revegetation** (see ch. 8).

Soil is handled in either one or two lifts. The latter requires that surface materials (usually A and B horizons) be segregated from subsurface (usually C horizon), and then redressed with the topsoil (A and B) over the subsoil (C). As a result, the more organically rich and biologically active materials are concentrated on the surface of the reconstructed soil, rather than being mixed with the less rich subsoil. This is an especially important consideration for very deep soils. The Montana and North Dakota programs both require two lifts, as does the Colorado program in some instances. Even in areas of thin soils, however, operators are beginning to appreciate the benefits derived from a two-lift system, and the procedure is being adopted more and more when the potential reclamation advantages outweigh the additional operational cost.

As an area or open-pit mine progresses, two lifts may be combined with direct hauling. In this case, topsoil from a small strip of land is first salvaged and stockpiled temporarily. Subsoil from that strip is picked up and applied to a backfilled area in the process of being reclaimed. Topsoil from the next strip is then picked up and applied over the redressed subsoil. This continues to the end of the salvage area, when the temporarily stockpiled topsoil is placed over the last band of redressed subsoil. **The combination of two lifts with direct hauling methods may provide the best species diversity in revegetation at mines with deep soils because it simultaneously preserves the biologically active materials and replaces them on the surface.** Where topsoil operations are contracted out, or where there is a dedicated fleet of reclamation equipment, this method is implemented more easily than at operations where scrapers are shared between topsoil operations and pit operations.

Box 3-D.—Soil Reconstruction for Reestablishing Ponderosa Pine[1]

The reestablishment of ponderosa pine is a sophisticated mine reclamation problem requiring special soil reconstruction. The ponderosa pine occur only on scoria knobs and resistant sandstone ridges; the mining process removes the substrate condition on which they depend. Their reestablishment requires the reconstruction of a thick layer of coarse, loose scoria or very gravelly soil over a compacted layer of spoil, and preferential planting on north-facing slopes, to obtain a substrate that is well drained but sufficiently moist to enhance early establishment. The compacted spoil creates a barrier to soil moisture movement and thus leaves a moist zone within reach of the roots. The coarse, loose material provides rapid infiltration. At one mine, soils taken from ponderosa pine stands are clinker-type soils, and will be replaced over compacted spoil in two lifts. The subsoil and topsoil will be applied loosely and ripped to reduce compaction. Mulch or herbicides have been used to reduce competition from herbaceous species, but winter predation by rodents and deer is a continuing problem. Containerized nursery stock grown from local seed has proven most effective, with an 80 to 90 percent survival rate. The oldest plantings (1978) have resulted in ponderosa pines 2 to 3 feet tall. Current densities are about 500 stems/acre. The Montana regulatory authority recently asked the mine to establish seedling tree densities of 1,000 per acre in order to provide a closed tree canopy for wildlife. Such densities would not be achieved from volunteer growth for over 30 to 50 years, but probably will be difficult to establish due to increased competition among the pines. To reduce the potential for competition problems, the operator plans to interplant in older areas of pine reestablishment.

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[1] See case study mines C in reference 12 and MT-1 and MT-2 in reference 13.

Federal regulations require that topsoil be redressed in a uniform thickness, consistent with the postmining land use. During premine planning, the volume of available soil is calculated and divided by the area to be redressed to get the average thickness of topsoil (see ch. 6). As discussed in chapter 8, however, **allowing non-uniform topsoil replacement may facilitate direct hauling and may provide greater vegetative diversity.** In the Western States, only the Montana legislation specifically mentions special reconstruction of soils with non-uniform depths as an alternative reclamation technique, although this method has been or will be permitted on a case-by-case basis at several mines in other parts of the study region (see boxes 3-B, and 3-O).

There are numerous methods of preparing the redressed topsoil for seeding and planting, and of preventing erosion. These include contour furrowing, ripping on the contour, surface pitting, disking, terracing, and mulching. For particular postmining land uses or unusual revegetation problems, special soil reconstruction methods are employed (see boxes 3-D, 3-G and 3-K). The redressed surface soil may be tested for fertilizer requirements prior to seeding (see "Revegetation," below).

Surface Water[7]

Surface water reclamation may involve both mitigation of impacts to water quantity and quality during mining, and restoration of the surface water hydrologic regime after mining is completed. Discharges from active mining or reclaimed areas to local streams may increase levels of total suspended solids (TSS) and total dissolved solids (TDS). Changes in postmining groundwater quality also can affect surface water quality where groundwater systems discharge to surface streams. Moreover, surface mining can either increase the water quantity in local streams due to discharges from the mine, or decrease flow due to impoundments and drawdowns.

Water Quality

Although current mining regulations do not specifically distinguish between perennial and ephemeral streams when establishing effluent limitations from point sources, the potential impacts from surface mining are very different for the two types of streams. The potential for increasing sediment loads in ephemeral streams is slight, due to their naturally high sediment levels during runoff events. Impacts on perennial streams can be significant, however, including increases in TSS due to accelerated erosion resulting from removal of the vegetative cover, stripping of topsoil, and construction of stockpiles, tipples, roads, and other facilities. In addition, increases in TDS levels in perennial streams may be caused by discharges of pit water or by the movement of groundwater through replaced spoils to discharge areas in perennial stream channels (see "Groundwater," below).

Effluent limitations for TSS are established under the Clean Water Act and SMCRA (see ch. 4). As discussed in chapter 8, **sediment control ponds generally are considered the best available control technology for meeting the TSS standards, although the effectiveness of alternative controls currently is being investigated.** Where sediment control ponds are used, they are classified as point sources and must be designed to meet effluent standards for runoff equal to or less than that resulting from a 10-year 24-hour precipitation event.[8] The effluent standards for point sources include limitations for pH, total iron, and total manganese, as well as TSS. To ensure that these standards are met, ponds are designed to store the entire 10-year 24-hour runoff volume. The water stored in such ponds is released gradually after it has been detained long enough to meet the effluent standards for point sources.

The principal control for TDS in Western surface mining is to ensure that soil and overburden materials containing soluble ions (primarily salts) are buried in such a manner that they will not reach surface receiving waters (or groundwater) in concentrations in excess of the applicable standards.

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[7] Unless otherwise noted, the material in this section is adapted from reference 14.

[8] A 10-year 24-hour precipitation event is the maximum amount of rain that could fall within 24 hours with a probable recurrence interval of once in 10 years, as determined by the National Weather Service.

A 1981 assessment of the cumulative TDS impacts from all anticipated mining and agricultural development on the Tongue River of southeastern Montana indicated that, even with intensive mining, the dissolved solids concentrations in the study area would not increase substantially, nor would they reach levels unfit for irrigation water (15). That assessment found that the Tongue River tributaries could experience significant increases in TDS, but the major tributaries already have dissolved solids concentrations considered unsuitable for irrigation. A similar cumulative impact assessment of the Yampa River and its tributaries found that the effects of mining are greatest during periods of low flow when high TDS loads due to groundwater discharge are not diluted by surface runoff. As in the Tongue River study area, impacts to the smaller perennial streams in the Yampa basin are expected to be the greatest, and could adversely affect the suitability of these waters for irrigation during average-to-low flows.[9]

Water Quantity

Individual mines have little impact on the quantity of surface water supplies in the Western States. The water that is used at a mine for dust control, coal preparation, etc., generally is drawn from aquifers below the coal being mined, and supplemented by water interrupted by the pit and water stored in sediment ponds. The drawdowns created by an individual mine seldom substantially impair the yields of nearby wells or flows in perennial streams. The disruption in surface-water supplies caused by the cumulative drawdown of several mines concentrated in one area is discussed in chapter 6. Additionally, water storage in sediment control ponds can decrease streamflows when the cumulative impacts of several mines within a drainage basin are considered (see ch. 8).

Unlike experiences in the East, mine discharges are seldom a problem in Western mining operations. In the semiarid Western environment, shallow aquifers likely to be intersected by the mine pit often are of limited extent, or are seasonal. Thus the volume of continuous or seasonal discharges from surface mines is small and easily borne by local stream channels capable of holding flows from much larger volume precipitation events. The low volume of these discharges also relieves the potential for impacts to water quality of the receiving streams.

Occasionally, some of the large mines in the Powder River basin have temporarily produced very large discharges from scoria bodies (cindery rock strata) breached during facilities construction or mining. For example, in 1976, a mine in this area pumped 6,000 gpm for several days from a saturated scoria pod encountered during excavation for a coal preparation plant. Discharge of this water into the Little Powder River, an intermittent stream, significantly altered the flow until the scoria was dewatered.

Restoration of Surface Drainage Systems

Replacement of an erosionally stable surface drainage system is critical to the long-term success of surface mine reclamation. Although not specifically addressed in SMCRA, regulatory authorities use the general legislative provisions for water quality protection, minimum disturbance to the hydrologic balance, and erosion control to require operators to include designs for the restoration of surface drainage systems in their permit applications (see ch. 6). A detailed hydraulic analysis of each restored channel also is required to ensure that postmining runoff velocities will not cause erosion. If the velocities are erosive, engineered controls such as riprap may be used, but States discourage the long-term use of engineered structures in permanent reclamation designs because they require maintenance after runoff events (see boxes 3-E and 3-F).

The extent to which mining affects surface drainage characteristics depends on factors such as stripping ratio, areal extent of mining, and mining methods. Mines that cover large areas or contain relatively small watersheds often must reconstruct entire drainage basins. The ultimate goal is to develop topographic characteristics that produce a system in equilibrium with respect to erosion and sediment transport (see ch. 6). Where

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[9] The data and methodologies for these cumulative assessments are discussed in chs. 5 and 6.

Box 3-E.—Reconstruction of a Surface Drainage on an Excess Spoil Disposal Area[1]

A mine permitted pre-SMCRA is constructing a fill area for excess spoil disposal within a surface drainage. Incised valleys in the area of the mine generally are narrow, V-shaped, and about 250 to 500 feet deep, with valley wall gradients of 40 to 100 percent. When completed, the valley fill will contain approximately 54 million cubic yards of overburden with an average slope of 3:1 (horizontal to vertical). The face will be topsoiled and revegetated, and mulching and contour furrows in conjunction with benches will be used to control erosion. The drainage being filled with spoil contained an ephemeral stream that drained to perennial streams downstream of the permit area. The stream channel has been relocated on the north side of the fill, with drainage from the face of the fill collected by ditches that slope gradually in the direction of the restored stream channel. The channel empties into a sedimentation pond at the bottom of the fill. The restored channel was designed to accommodate the 100-year runoff event based on the ultimate maximum drainage area when reclamation is complete. The restored channel will be completely lined with riprap due to potentially erosive velocities (6 feet per second) during the design event.

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[1] See case study mine Q in reference 14.

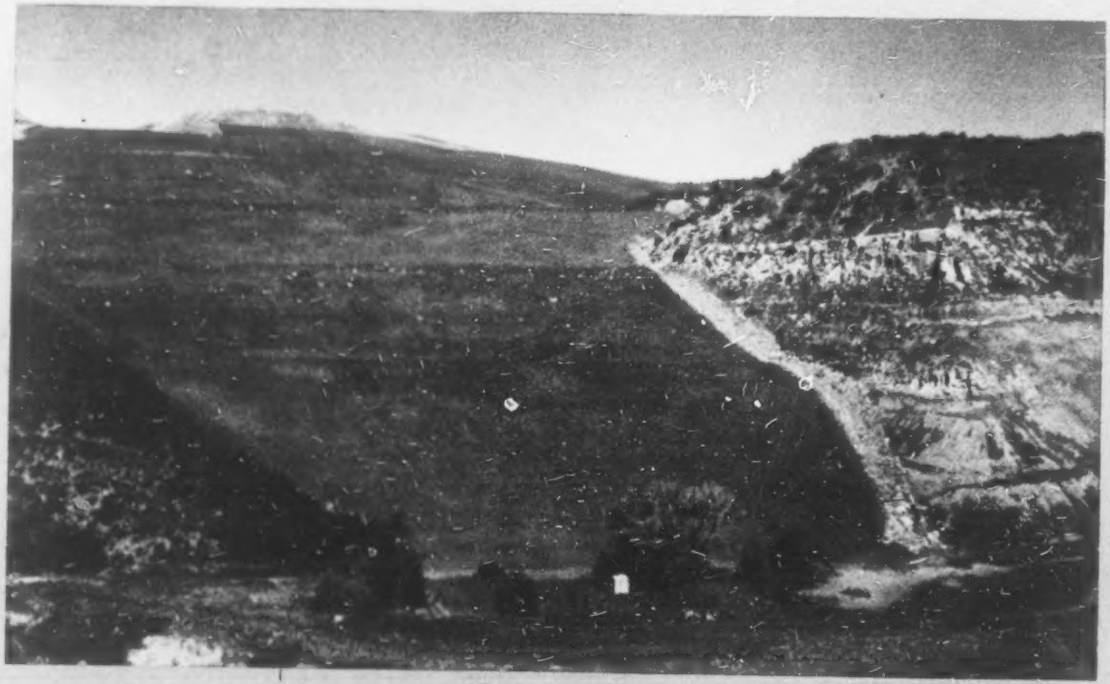

Photo credit: Colowyo Coal Co.

This excess spoil disposal area occupies a former stream valley. Note the cross-slope channels draining into the reconstructed drainage (right center), which is lined with riprap and drains into a sedimentation control pond (lower right).

Box 3-F.—Design and Construction of a Permanent Diversion[1]

Surface water restoration at a mine in New Mexico includes a permanent diversion for the major arroyo draining the permit area, sized for the 25-year 24-hour precipitation event. The arroyo is ephemeral above the permit area, intermittent below, and drains into a perennial river about 0.75 miles south of the mine. Prior to construction of the diversion, the operator analyzed sediment transport and deposition, and runoff volumes and peak flows for various precipitation events. The diversion channel was then sized to provide a transport capacity approximately 3 percent greater than the sediment discharge of the arroyo. The diversion channel is riprap-lined for most of the length, and includes two riprap drop structures. The construction, operation, and maintenance of the diversion in this arid area will provide valuable information for the design of reconstructed surface drainages postmining. In 1981 (after the original design was permitted), the Federal and State regulatory authorities concluded that the design should include criteria to ensure the diversion would be in equilibrium with the stream channels above and below. To accomplish this, the channel was redesigned to maintain the existing channel gradients, maintain subcritical flows during a 100-year 24-hour storm, maintain TSS levels throughout the diversion length, hold the minimum bankfull capacity of the undisturbed up- and downstream channels, and allow the riprap structures to adjust to the existing hydrologic regime. Construction was completed in 1983. Since then, one major precipitation event has occurred with a flow less than 3 feet in depth; it resulted in 4- to 5-foot deep cuts over 150 to 200 feet of the east bank of the diversion. The regulatory authority attributed the erosion to the lack of riprap on the east bank and along the entire bottom of the diversion. A monitoring program has been developed to provide evaluation criteria for the diversion, and to ensure that excessive erosion does not occur, and that the diversion and mined areas remain stable. The operator is developing a mitigation plan for excessive erosion. A continuing uncertainty is the stability of the riprap during runoff events.

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[1] See case study mine R in reference 14.

the stripping ratio is high, the postmining topography often will very nearly duplicate premining topography, and it may be possible to restore the premining surface drainage system to its approximate original configuration. Provided that the premining erosional stability of the drainage system was not dependent on geologic features that are removed during mining, such as bedrock outcrops, restoration of stream channels may simply be a matter of restoring premining channel slopes, cross sections, and bed form.[10]

In other areas, such as the Powder River basin, low stripping ratios may preclude restoration of a drainage system to its original configuration. In these areas, entire drainage systems must be built on the restored surface, based on a complete quantitative analysis of the geomorphology of the premining and postmining drainage basins. Where the overburden is extremely thin (relative to the coal seam thickness), it may be difficult to establish any surface drainages, and permanent topographic depressions may remain.

In cases where mining removes only a segment of a stream channel, restoration involves duplication of the undisturbed channel with no abrupt changes in slope as well as nonerosive slopes (see box 3-F). If necessary to achieve acceptable slopes, channels and flood plains are reconstructed in a winding configuration ("sinuosity") to spread the change in elevation over a longer distance. If the channel is alluvial, special attention must be paid to the size and gradation (size composition) of the bed material in order to maintain the sediment transport rate and ensure channel stability. For channels stabilized with vegetation, the ability of the bed and bank to support a viable vegetation community is the critical factor.

Special surface water restoration techniques may be used in innovative or unique reclamation situations. These include channel reconstruction through natural scouring and deposition processes, engineered reconstruction of winding

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[10] Bed form includes channel bed characteristics such as particle size gradation for alluvial channels, or the presence of perennial sod-forming grasses for stabilized channels.

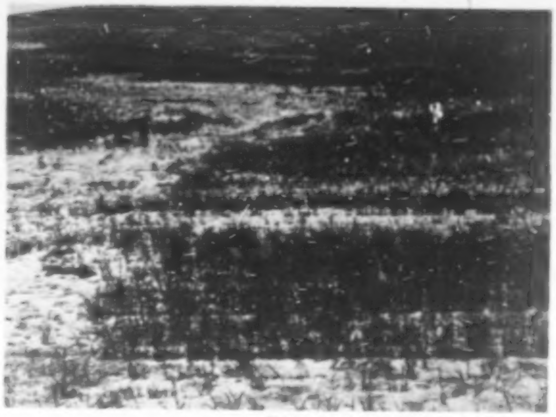

Photo credit: Jenifer Robison, OTA staff

At this Wyoming mine, a small drainage basin was reconstructed with a winding drainage proceeding from the upper center of this picture to the lower left. Millet was planted to stabilize the topsoil until the appropriate season for applying the permanent seed mix.

drainages, and restoration of wetlands (box 3-G). In these situations, the criteria for evaluating the success of the reclamation become extremely important (see ch. 7).

Groundwater[11]

Surface coal mining affects groundwater resources both during and after mining in ways that vary with the mining method, the extent and scale of mining, and the characteristics of the hydrogeological system. **Mining activities can lower water tables and reduce groundwater quality, either of which could result in impacts to the existing ecological system** (ch. 6 discusses the analytical techniques used to predict these impacts). Surface mining regulations require the operator to monitor groundwater characteristics for at least 1 year prior to the start of mining, in order to establish a baseline against which the impacts of mining can be measured (see chs. 4 and 5).

Groundwater Quantity

Shallow aquifers in coal seams and overburden strata in the Western States provide water for both stock and domestic uses from wells that typically

Box 3-G.—Reconstruction of Wetlands[1]

A North Dakota lignite mine permit area contained 15 wetlands prior to mining. The operator surveyed the landowners to determine their preferences about which wetlands to restore, to what land use they should be restored, and which wetlands to eliminate. Based on the results of this survey, 2 of the wetlands will not be disturbed, 10 will be eliminated, 3 will be reconstructed to be hydrologically equal to their premining condition, and 2 new wetlands will be designed based on areal hydrologic data. Definition of the premining chemical and physical characteristics of the wetlands was difficult because many of these characteristics vary widely over time and with climatic conditions. Premining vegetation was surveyed in the three wetlands to be reconstructed, and the geology of the wetland basins and their soil types were identified. A postmining basin shape was designed to provide both the vegetative diversity desirable for wildlife use and adequate water storage to minimize the probable downstream hydrologic consequences. Based on the design water depths and the basin configuration, the operator expects a vegetational succession of aquatic plants that ultimately will provide cover for water-nesting birds as well as nesting and foraging for other birds and mammals. Because of the unique nature of this restoration, OSM stipulated that the operator develop standards for reclamation success. These standards are based on an assessment of water quality and quantity, vegetation community patterns indicating levels of diversity, and wildlife use patterns. Revegetation appears relatively easy to accomplish, due in part to the ability of many wetland plant species to spread from rootstock or cuttings. Native vegetation plugs from nearby wetland areas are transplanted. The operator also appointed a Wetlands Advisory Committee that will review all monitoring data, conduct onsite inspections, and make recommendations to the operator on restoration techniques and criteria for success. It is unclear what action will be taken if the advisory committee or the regulatory authority determines that wetlands are not restorable.

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[1] **See case study mines: A in reference 12; C in reference 14; ND-2 in reference 13; and A in reference 1.**

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[11] Unless otherwise noted, the material in this section is adapted from reference 14.

yield 5 to 10 gpm, a flow rate insufficient for irrigation. Exceptions are wells developed in the alluvial aquifers of major streams, such as the Tongue and Missouri Rivers, where much larger yields are possible. In any case, State water laws and the Federal and State regulatory programs require the mine operator to replace the water supply or to otherwise compensate the owner for the water lost if mining activities dewater any nearby wells to the extent that they are no longer usable.

During and after mining, aquifers in the overburden and coal are destroyed and replaced by mine spoils. Usually the coal seam itself would have been the only shallow aquifer of any significance. **Tests conducted on wells developed in postmine spoils in several Western mining areas suggest that the spoils will be at least as capable of transmitting water as were the coal seam aquifers that have been removed.**

Mining method, which together with lithology determines the swell factor (the ratio between the volume of postmining spoils and premining overburden) in the replaced spoils, partially influences the degree to which an aquifer's premining hydraulic characteristics are restored postmining. Swell factors range from 5 to 10 percent for small scraper mines, 10 to 15 percent for truck-and-shovel mines, and 20 to 30 percent for dragline operations. There is a general correlation between increase in postmining volume and an increase in porosity and hydraulic conductivity. For permit approval, the operator is required to evaluate both the sources and the rate of recharge to the postmine spoil aquifer (see ch. 6).

Spoils aquifer recharge and groundwater discharge to surface waters are affected by postmining surface topography. At thin overburden mines, for example, postmining topography may be lower than the premining surface, and unless the backfill is sealed to create a confined aquifer, a lake or swamp could form on the surface. At a mine in Wyoming, where modeling showed the potential for the postmining water table to be approximately 10 feet below the surface, the postmining topography will be designed with small stream channels at least 10 feet deep to drain surface water, intercept the water table, and keep the majority of the surface from being saturated (see also box 3-H).

Groundwater Quality

Mining breaks up shales and sandstones and exposes fresh mineral surfaces for leaching, which will affect the quality of the water that flows through these materials. Because groundwater flows toward the pit during mining, there is little opportunity for any contaminants introduced by mining to affect offsite areas, and impacts to groundwater quality ***during*** mining are minimal (see ch. 6, figs. 6-1A, B).

The greatest potential for groundwater quality impacts occurs ***after*** mining, when groundwater saturates the spoil and returns to a steady-state groundwater flow pattern (fig. 6-1C). Water quality is expected to be degraded in the resaturated spoils until they have been leached by sufficient volumes of water to establish a chemical equi-

Box 3-H.—Burial of Unsuitable Spoil so as To Prevent Groundwater Contamination[1]

At a mine in Montana, the postmining TDS concentrations in the groundwater in resaturated spoils are around 1.5 times greater than in the premining aquifers. The principal constituents in the spoils groundwater are magnesium and sulfate, although lead and nickel concentrations also are higher in the groundwater of reclaimed areas than in undisturbed areas. The higher TDS levels are attributed to elevated concentrations of these elements in the overburden and interburden. As a result, the operator has committed to burial of interburden below at least 8 feet of suitable spoil material, but above the postmining water table and away from reconstructed drainages. Protection of postmining groundwater quality is further provided in the permit application by plans to construct spoil surfaces that are well drained by channels. With this design, the precipitation falling on reclaimed spoil surfaces will be less likely to infiltrate the spoils deeply, and therefore less likely to leach the undesirable chemical constituents into the groundwater system.

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[1] See case study mine F in reference 14.

librium between incoming water and soluble constituents in the spoil material. **Over the long term, however, groundwater quality is still predicted to be suitable for the majority of postmining land uses.**

The soluble constituents primarily responsible for elevated TDS levels are the salts of sodium, calcium, and magnesium, as well as sulfate and bicarbonate. The worst impacts on postmining groundwater quality could result from placement of unoxidized sodic and sulfide-rich sediments near the surface—above the water table—where water from surface infiltration could contact these sediments en route to the groundwater table. In this situation, surface infiltration must be limited to prevent adverse impacts to groundwater quality (box 3-H). While acid-mine drainage has long been a problem in the Eastern United States, it is just beginning to be recognized in Western mines (see box 3-I), where the overburden is much more likely to be high in carbonate minerals (calcite and dolomite) with a high buffering capacity (see ch. 8).

The principal reclamation technique to control TDS and other groundwater contamination is special handling of the overburden (i.e., selective placement or mixing). At present, however, researchers are divided in their opinions on the technique for the burial of overburden in mine spoils in order to minimize impacts to groundwater systems.

When wastes (e.g., fly ash or scrubber waste from powerplants) are buried in the pit, concerns about groundwater quality increase. Soluble metals in the coal can be concentrated in the ash and, under certain conditions, mobilized by groundwater. As with other chemically unsuitable spoil materials, special handling is required in burial of utility wastes. A mine in New Mexico buries fly ash, bottom ash, and scrubber sludge in low permeability mine spoils below the postmining water table (see box 6-F), while a mine in northwestern Colorado is required to dispose of utility wastes in dry mine spoils above the postmining water table (see box 3-J).

At the Wyodak Mine near Gillette, Wyoming, thin overburden conditions necessitate disposal of fly ash beneath the postmining water table. Due to concerns about the permeability of the spoils, the Wyoming DEQ requires that the ash material be encapsulated in compacted clay cells to minimize impacts to groundwater quality. Chemical analysis of the ash, column-leaching studies of the ash and ash-overburden mixtures, and accelerated-aging studies of the compacted clay liners were required to document that this disposal method would minimize groundwater quality degradation (see ch. 6 for further discussion of these analytical techniques).

Box 3-I.—Handling of Acid-Forming Material[1]

The overburden and coal seam at a Powder River basin mine have layers of carbonaceous material containing pyritic and organic sulfur that can produce acids when oxidized. The regulatory authority was concerned about incorporating this material in spoil below the postmining water table because of the possibility of producing acidic groundwater. Analysis of the acid-base potential of the carbonaceous materials (see ch. 8) indicated that the materials would pose no hazards to groundwater quality. The carbonaceous material will be mixed with highly basic spoils to dilute the acid-producing potential of the backfill. The top of the regraded backfill must consist of suitable material, as demonstrated by sampling and analysis of the top 4 feet, which can include carbonaceous materials in low concentrations.

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[1] See case study mine M in reference 14.

Alluvial Valley Floors[12]

Alluvial valley floors (AVFs), as defined in SMCRA, are "the unconsolidated stream-laid deposits holding streams where water availability is sufficient for subirrigation or flood irrigation agricultural activities" (sec. 701). In the Western United States, SMCRA prohibits surface coal mine operations that would interrupt, discontinue, or preclude farming on AVFs significant to agriculture, unless the acreage to be disturbed is so small as to have a negligible impact on farming. The Act also prohibits mining that would materially

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[12] Unless otherwise noted, the material in this section is adapted from reference 14.

Box 3-J.—Disposal of Powerplant Waste in the Mine Pit[1]

Groundwater quality concerns about disposal of fly ash, bottom ash, and scrubber sludge at a mine in northwestern Colorado arose when column leach studies indicated that water percolating through the waste could produce leachate concentrations of aluminum, barium, chromium, sulfate, boron, and molybdenum in excess of the Environmental Protection Agency's primary and proposed secondary drinking water standards and recommended limits for irrigation water. The premining water quality in the main aquifer in the area was classified as poor for domestic use and good for irrigation and livestock use. The aquifer will be removed in the northern limits of the mine, and at the end of mining the exposed portion of this aquifer at the northern pit face will be in direct contact with the spoils. If contamination occurs, water from the mine area could enter this aquifer, and seven bedrock wells and two alluvial wells might be affected. Following review of the column leaching studies, the regulatory authority stipulated in the permit that the waste material be buried above the projected postmining water table, and certain areas of the pit were designated as unsuitable for utility waste disposal. Under this disposal plan, only one source of water could contact the waste: infiltration and deep percolation of precipitation. From the results of a monthly water balance computation, the operator concluded that during a typical year no deep percolation through the spoils from precipitation infiltration will occur. Moreover, based on historical weather data and the average percolation rate of approximately 1.6 cm/yr, the operator calculated that from 500 to 1,000 years would be required for percolating water to reach the wastes. In addition, the analysis suggested that little of the percolating water ever would contact the waste because the water would flow down the path of least resistance. At this mine, the spoil material, which is 10 to 100 times more permeable than the waste, would provide a path for the percolating water.

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[1] See case study mine P in reference 14.

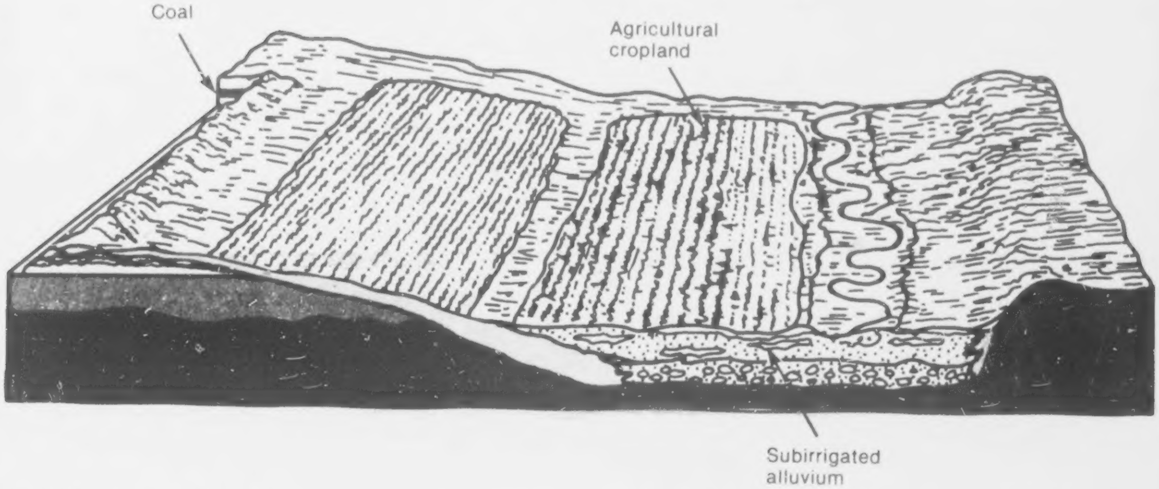
damage the quantity or quality of surface or groundwater systems that supply AVFs significant to farming. Where mining is allowed, either because the AVF is not significant to agriculture or because the area to be disturbed is very small, SMCRA imposes special reclamation standards to preserve or restore the essential hydrologic functions of the AVF. A special monitoring system also is required for all AVFs from the onset of mining until all bonds have been released. Figure 3-10 presents a stylized diagram of an AVF.

The hydrologic functions unique to AVFs include the collection, storage, and regulation of flow that results in water being usefully available from the stream or alluvial aquifer in quantities sufficient for agricultural purposes. As yet, no AVFs have been mined and finally reclaimed under SMCRA. However, several plans for AVF restoration have been approved by the regulatory authorities. These plans focus on channel and floodplain geometry and erosional stability, and on alluvial aquifer depth, thickness, and water storage and transmitting capabilities. Thus AVF restoration combines some of the more rigorous design aspects of surface and groundwater restoration discussed previously (see box 3-K).

Design of the restored channel and floodplain is essentially the same as described under "Surface Water," above, except that the drainage basin must be of sufficient size to sustain the premining surface water irrigation capability. This usually is not a problem, because drainage basins large enough to contain an AVF in the semiarid West normally are much larger than a mine area. Moreover, topography adjacent to the AVF typically is flatter after mining, increasing its value for irrigation.

The simplest plan for restoration of an alluvial aquifer is to salvage and replace alluvial materials present in the undisturbed valley. These materials ordinarily range from very fine-grained deposits near the surface to coarser-grained sands and gravels at the base of the deposit. Often there are fine-grained sequences mixed within other layers. Due to mixing, salvage and replacement of these materials may not restore the premining hydraulic properties of the material. There-

Figure 3-10.—Stylized Diagram of an Alluvial Valley Floor



SOURCE: Dollhopf, Wendy, Goering, and Hedsberg, "Hydrology of a Watershed With Subirrigated Alluvial Materials in Crop Production," Montana Agricultural Experiment Station Bulletin 715, 1979.

Box 3-K.—Techniques for Restoring the Essential Hydrologic Functions of an AVF[1]

A mine in the Powder River basin has an AVF not significant to farming running through the center of the permit area. The majority of the AVF acreage lies adjacent to an intermittent stream, and minor acreages adjoin small ephemeral tributary channels. Subirrigated areas were found to cover about 10 percent of the unconsolidated stream-laid deposits. Artificial flood irrigation currently is not practiced within the area to be affected by mining, but over 100 acres of land adjacent to the intermittent stream has suitable soil quality, water quality and quantity, and topography to be potentially flood-irrigable. The operator will employ special measures to restore subirrigation along the reclaimed portion of the intermittent stream. All coarse-textured alluvial deposits found along the intermittent stream will be salvaged and stockpiled separately, and subsequently replaced in the reconstructed channel so as to facilitate subirrigation and hydrologic communication between the reconstructed and undisturbed portions of the stream. Reclamation also will attempt to extend subirrigation to an 80-foot-wide reclaimed low flow channel. The AVF area also received discharge from the premining coal and overburden aquifers, which helped to maintain the groundwater levels in the valley floor and thereby helped support subirrigation. The operator is placing a compacted clay soil layer beneath the restored alluvial aquifer in order to isolate the restored alluvial system hydraulically from the remainder of the spoils, and thus help to shorten the time for subirrigation to be reestablished. Subirrigation and hydraulic communication between the reconstructed and undisturbed portions of the intermittent stream will be promoted by the placement of a 10-foot thick layer of coarser-grained alluvial material beneath 2 feet of suitable topsoil, above 10 feet of suitable overburden, and above the compacted clay soil layer in the 80-foot wide reconstructed active low flow channel. Separate overburden stockpiles have been established for suitable alluvial material to ensure that a sufficient amount will be available for channel reconstruction. Reestablishment of subirrigation will be demonstrated by the extent and variation of plant species, along with other hydrologic indicators of restoration of the alluvial water levels.

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[1] See case study mine J in reference 14.

fore alternate materials, such as sandy overburden, may be used in AVF reconstruction. Most AVF restoration plans include a compacted layer beneath the replaced alluvium to minimize loss of streamflow into the spoils. In addition, this layer should help speed up restoration of the essential hydrologic functions of the alluvial system by making its restoration relatively independent of that of the adjacent spoils (see box 3-K).

Revegetation[13]

The goal of revegetation at Western surface coal mines is to reestablish plant communities similar to the premining vegetation (as determined by baseline vegetation maps and quantitative data for all land-use categories), except where the postmining land use is different from the premining use, or where the premining vegetation was of poor quality and thus represents an unacceptably low standard for revegetation. The range of natural vegetation within the study region is broad, with a concomitant variation in the permitting process and subsequent approaches to revegetation. The desert grasslands of northwestern New Mexico, for example, present significantly different revegetation problems from the mountain brush in northwestern Colorado, the mixed prairie in northeastern Wyoming, the ponderosa pine woodlands of southeastern Montana, and the woody draws along drainages in North Dakota. Plant communities along drainages are especially important in much of the region, because the moister conditions frequently support greater vegetation densities and diversities than drier uplands, and may foster plant and animal species not found elsewhere.

Once the redressed topsoil has been graded and prepared for revegetation (see discussion of "Topsoil Handling," above), the area is seeded and planted with species appropriate for the postmining land uses—primarily native species for rangeland and wildlife habitat. The timing of seeding and planting is determined by site-specific moisture and climatic conditions, as well as vegetation types (see below). The seed mixes generally are chosen by the operator in consultation with the regulatory authority, and are specified in the approved permit. The seeds may be applied through broadcast or drill methods. Shrubs and trees can be established from nursery stock, including bare-root and containerized stock; from planted or in-situ seeds; or from onsite transplants. In some areas, special management practices may be used to promote revegetation success (see discussion below and in ch. 8).

The site-specific factors that affect revegetation include soil texture, depth, and alkalinity; site elevation, slope, aspect, and wind exposure; and precipitation and temperature patterns and ranges. Plant-available moisture, as determined by the amount, form, and seasonal distribution of precipitation, is usually the primary limiting factor for plant growth and successful revegetation. As discussed at the beginning of this chapter, seasonal precipitation varies widely in the study area, with annual averages at most mine sites ranging from approximately 7 or 8 inches to 16 or 18 inches (fig. 3-2). Plant-available moisture usually is at a maximum in late spring to early summer for most of the study area, but peaks in mid to late summer in the San Juan River region.

The combined patterns of plant-available moisture and temperature determine whether cool season plants, which carry out most of their growth before or after the heat of summer, or warm season plants, which start and accomplish their growth at warmer temperatures, are dominant. In either case, the maximum period of growth coincides with the maximum precipitation. In general, cool season species are dominant in the central and northern portions of the study region, and warm season species prevail in the southern reaches.

Special Management Practices

A variety of special management practices may be used to promote revegetation success and meet performance standards. These may range from relatively common agricultural practices adapted for mined land reclamation, such as mulching, irrigation, and fertilization; to direct-haul topsoiling; to innovative techniques to reduce interspecies competition, enhance woody plant density, improve grassland quality, and promote landscape diversity. The use of any of these practices will depend on site-specific conditions and the postmining land use, as well as on mining methods.

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[13] Unless otherwise indicated, the material in this section is adapted from reference 13.

As discussed above, ***direct haul topsoil* provides an organically rich and biologically active medium for revegetation, which dramatically improves the establishment of planted and volunteer species.** As a result, superior lifeform (i.e., shrubs, forbs, grasses) and species diversity can be obtained within a relatively short time. In areas with deep soils of suitable chemical and physical parameters, the benefits of direct haul topsoil may be enhanced with the use of two lifts (see ch. 8).

***Mulch* conserves soil moisture and aids erosion control, and has long been an integral part of surface mine revegetation.** Historically, the most common mulching materials have been straw or hay. Although these materials are effective in erosion control, they often are difficult to anchor in windy areas, and the usual anchoring technique of crimping the straw into the soil may cause more soil moisture to be lost through wicking than it conserves. Considerable nitrogen also is tied up in the decomposition of the mulch. Furthermore, straw or hay mulches tend to include seeds of undesirable species, and the resulting weed infestations can cause serious competition with the planted species. Those native hay mulches that have proven to be relatively weed-free can include desirable native seeds that otherwise may be hard to obtain. Reliable sources of native hay are scarce at many mines, however.

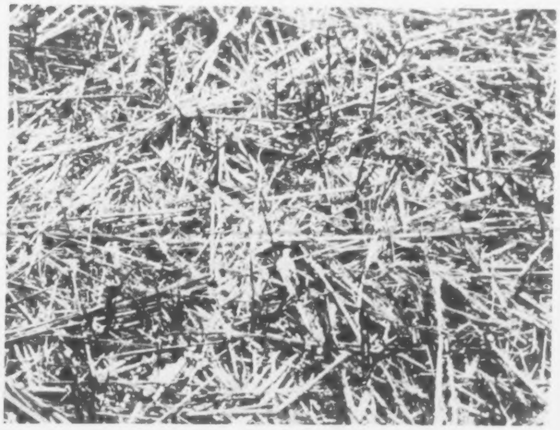

Photo credit: Office of Surface Mining

Straw or hay mulch can conserve soil moisture and aid in erosion control until revegetation is established. Here, grass may be seen coming up through the mulch.

Alternative approaches include the use of mulch created onsite and "stubble" mulch. Mulch derived from shredded native vegetation ("live mulch") has shown good results in promoting woody plant density and diversity at one mine in northwestern Colorado, where the climatic and other conditions for revegetation are the most favorable in the study region (see box 3-L). This promising technique is now being tried in the more arid conditions of northwestern New Mexico.

For stubble mulch, a cover of small grain (e.g., wheat, barley, millet) is drill-seeded in the spring to retard wind and water erosion. The following

Box 3-L.—Creating Mulch From Native Vegetation[1]

A mine in northwestern Colorado "creates" mulch before topsoil removal by treating woody areas with a tractor-mounted shredder that leaves a residue of finely chopped woody biomass on the soil surface. The shredder can operate in the aspen woodlands, producing as much as 77 tons of mulch per acre. This technique allows complete topsoil salvage in areas where woody plants formerly were uprooted and removed by bulldozers. The uprooted plants had substantial amounts of the uppermost (and most valuable) soil layers left attached to the root system. This rich soil and accompanying root material were lost as the plants were hauled away for disposal. Areas treated by this mulching technique have shown substantial woody-plant regeneration by root sprouting, resulting in far better densities than previously achieved through seeding and planting. Moreover, after topsoil removal and replacement on the reclaimed surface, sufficient organic debris remains on the surface to function as a mulch, and the regulatory authority has approved this innovative "live" mulching in lieu of other traditional mulching methods at this mine (see also box 8-B).

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[1] See case study mine CO-1 in reference 13.

fall, the grain "nurse" crop, which may be mowed to prevent seed production, is present as standing dead straw, and the perennial seed mix is interseeded between the rows of remaining stubble. During the winter, the stubble enhances snow retention, and as a result, the perennial seed mix germinates and grows in a more favorable environment than if the stubble were not there. On at least one mine, grain crops have been grown for several years, and the stubble disked into the soil in hopes of enhancing organic-matter content prior to seeding the perennial mix.

Early concern about revegetation success in areas with less than 10 inches of annual precipitation led to the imposition of *irrigation* requirements in a number of mine permits. Irrigation can ensure consistent and predictable plant establishment, especially in the Southwest where precipitation is less effective in promoting plant growth because it occurs later in the year and under warmer conditions, resulting in more precipitation loss by evaporation. However, vegetation growth developed under irrigation normally experiences a substantial dieback when the irrigation is withdrawn. Moreover, in such low-precipitation areas, irrigation water of acceptable quality is likely to be difficult to obtain (see box 3-M).

Vegetation developing slowly under dryland conditions may reach the same level of cover and production in the long run as irrigated areas. A mine in northwestern New Mexico that receives as little as 6 to 8 inches average annual precipitation uses irrigation for 2 years after seeding as part of its standard reclamation practice. On part of another mine in the same area owned by the same company, an experimental area without irrigation has been initiated and will be monitored to determine the relative success of revegetation with and without irrigation.

***Fertilization* of revegetated areas has diminished steadily because pasture species dependent on high fertilizer rates have been removed from seed mixes, and because experience has indicated that nitrogen fertilizers encourage vigorous growth of weeds and the more aggressive native grasses, to the detriment of less aggressive natives, including woody plants.** At most sites, performance standards can be met through other management practices, and the enhanced short-term production and cover resulting from fertilization are not needed for long-term revegetation success.

Box 3-M.—Supplemental Irrigation[1]

At a mine in southwestern Wyoming with annual average precipitation of 7 inches, a permit stipulation required irrigation to ensure successful revegetation. The streams in the mine area are all ephemeral, and available surface water derived from runoff is likely to be of poor quality due to the combination of intense rainfall, low natural vegetation density, erosive soils, unstable stream channels, and extremely transient, highly peaked streamflows. As a result of the poor quality of water available at the site, the permit stipulation also required the operator to develop a less salty irrigation water supply or demonstrate that the existing water quality would not damage soils or vegetation. No better water source became available, and use of the surface water on test plots showed deleterious salt buildup. While both the search for better water and studies of the effects of salinization continued, revegetation was attempted without the use of supplemental irrigation. Results to date show values of cover and production roughly comparable to the established performance standards based on premining vegetation. Based on monitoring data for unirrigated revegetation areas, the regulatory authority granted relief from the permit stipulations for the duration of the 5-year permit, but irrigation requirements could be reinstated at the time of permit renewal.

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[1] See case study mine I in reference 14 and WY-3 in reference 13.

A number of steps may be taken to *reduce interspecies competition* between aggressive cool season grasses and the various shrubs, forbs, and warm season grasses that frequently are unable to survive beyond germination. Two commonly used planting remedies are to reduce the relative proportion of cool season grasses in the seed mix in order to offset their competitive advantage, and to use two-staged or two-phased planting for temporal separation in the establishment of aggressive and less aggressive species. Two-staged or two-phased planting was first practiced at a mine in southeastern Montana, where warm season grasses plus forbs and shrubs are planted in prepared topsoil, and then given one to three growing seasons to become established before interseeding with cool season grass species. Alternatively, sequential drill-seedings at an angle to one another provide a slight—but apparently effective—spatial separation of aggressive and less aggressive species. Another successful approach is to plant both cool and warm season species during the warm season to reduce the competitive advantage of cool season grasses, and then use supplemental irrigation to maximize the growth of warm season species. Also, lower total planting rates associated with direct haul topsoiling typically have improved the establishment of less aggressive species.

***Revegetation of woody plants* in sufficient density and diversity to meet performance standards is a continuing concern in the West, especially in areas where woody plants are important winter browse for big game.** Loss of newly established shrubs to wildlife is a continuing problem. However, monitoring and other revegetation data at a number of mines in Wyoming suggest that shrub densities of one stem per square meter over 10 percent of the area (the proposed standard in Wyoming) can be realized in the early years of reclamation using direct seeding combined with one of the methods for reducing competition discussed above. In general, the greatest success has been achieved with four-wing saltbush. Other shrubs valuable as browse have had variable success, and big sagebrush has proven especially difficult to establish at many sites (see ch. 8). Planting of nursery stock and onsite transplants of mature shrubs may be too expensive and results too poor at some mines for large-scale use of these techniques, unless supplemented with direct haul topsoiling, which can provide a valuable source of seeds or rootstock ("propagules") for shrub volunteers. In addition, as noted above, mulch created from shredded native woody vegetation has shown promise as a propagule source in northwestern Colorado, although its effectiveness in other parts of the study regions has yet to be demonstrated. Several mines in northwestern Colorado also are transplanting shrub and tree pads directly with a front-end loader, which may provide volunteer growth later in the liability period.

Several special management techniques are being used on *upland grasslands* in the Northern Great Plains to improve lifeform and species diversity, seasonality (particularly warm season grass establishment), and vigor. In the Northern Plains, grasslands comprised of highly productive species may become stagnant and less productive if excess litter (decayed organic matter) accumulates, because litter ties up nutrients and can promote disease. Grazing is one technique for breaking up the litter and incorporating seeds and organic matter into the soil. Burning also can increase nutrient availability temporarily and hasten breakdown of the litter. Grazing, burning, haying, and application of herbicides may improve diversity (including seasonality) when the timing and intensity of these practices decrease the advantage of cool season grasses and "weeds."

Wildlife[14]

Techniques or practices to alleviate surface coal mining impacts to wildlife include mitigation techniques during mining as well as habitat restoration postmining. A mine operator will select a set of techniques in consultation with the regulatory authority and relevant wildlife agencies (e.g., U.S. Fish and Wildlife Service—FWS, State Fish and Game agencies), **given the baseline data on species occurrence, distribution, and abundance, habitat preference, and reproductive success, and on habitat or habitat features considered limiting or critical to the survival or maintenance of a particular species population** (see ch. 5). Important terrestrial habitats in the study region include raptor nest sites, critical big game winter range, sharp-tailed and sage grouse breeding grounds, bald eagle winter concentration areas, and sandhill-crane nesting habitat, as well as habitat for threatened and endangered species. Aquatic habitat potentially

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[14] Unless otherwise noted, the material in this section is adapted from reference 1.

Table 3-3.—Selected Mitigation Techniques Listed by General Category[a]

Avoidance	Operational	Habitat replacement/enhancement	Offsite enhancement
—Preserve vegetation patches[b] —Preserve important habitat[b] —Buffer zones —Temporal avoidance during critical periods or times —Visual barriers —Protect migration corridors[b] —Stagger operations to avoid disturbing large tracts of habitat concurrently	—Restrict speed limits on access and haul roads —Compatible location of roads —Underpasses/overpasses for roads and conveyors —Raptor-safe powerlines —Compatible fence design or lay-down fence for big game —Employee wildlife awareness programs —Hunting and fishing allowed/not allowed —Prohibit firearms in vehicle —Monitoring	—Topographic manipulation[b] • undulating surface • surface depressions • drainage reconstruction • microtopographic features —Establish/enhance impoundments[b] —Rock piles/boulders —Transplant shrubs/trees —Establish shrub patches —Establish interspersion/edge concept with vegetation reestablishment —Establish shelterbelts/riparian vegetation —Direct application of topsoil —Attain shrub density standards[b] —Brush piles[c] —Implant dead trees for snags[c] —Stream habitat reconstruction —Improve land management practices —Nesting structures[c] —Leave/modify highwalls[b] —Relocate raptor nests[b] —Relocate sage grouse strutting grounds —Special studies/research —Perch sites[c] —Gallinaceous guzzlers[c] —Vegetation species selection	—Controlled burning —Fertilizing[c] —Seeding —Shrub thinning or crushing —Elimination or reduction in livestock grazing —Impoundments[b] —Strutting ground relocation —Relocate raptor nests[b]

[a] For detailed descriptions and discussions of these techniques, please refer to the list of selected references in reference 1.
[b] Legal, technological, and/or economic constraints limit the extent to which these practices may be employed.
[c] Temporary techniques that require maintenance beyond installation.

SOURCE: Cedar Creek Associates, "Wildlife Technologies for Western Surface Coal Mining," contractor report to OTA, August 1985.

affected by surface coal mining consists mostly of small wetlands, stockponds, perennial streams, and ephemeral drainages.

Under SMCRA, operators must, to the extent possible using the best technology currently available,[15] minimize adverse wildlife and habitat impacts. The Federal regulations add provisions related to endangered species, bald and golden eagles, wetlands and habitats of unusually high value, and specify design standards for features such as powerlines, haul roads, and fences.

Mitigation Techniques

There are four general categories of techniques for mitigating wildlife impacts from surface coal mining: habitat replacement/enhancement, avoidance techniques, operational techniques, and offsite enhancement. Table 3-3 summarizes the measures more commonly employed at Western surface coal mines for each of these categories.

***Habitat replacement and enhancement* during reclamation comprise the greatest number of wildlife mitigation measures.** All mining operations give some consideration to wildlife in planning revegetation and other reclamation activities. Where wildlife habitat is the primary postmining land use, or where sensitive or protected species will be disturbed, wildlife habitat replacement or enhancement may be complex and extensive (see box 3-N). For those portions of the mine site where the primary postmining land use is wildlife habitat, SMCRA requires that plant species for revegetation be selected based on their proven nutritional value, their use as cover, and their ability to support and enhance

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[15] In this context, "best technology currently available" is defined in the Federal regulations as "equipment, devices, systems, methods, or techniques which will minimize, to the extent possible, disturbances [of] and adverse impacts on fish, wildlife, and related environmental values, and achieve enhancement of those resources where practicable."

Box 3-N.—Habitat Replacement and Enhancement Techniques[1]

The premining surface at a mine in northeastern New Mexico was managed specifically for big game, primarily elk and mule deer. The primary postmining land use will be wildlife habitat, as specified by the surface owner, who maintains a strong economic interest in resident big game herds. Other big game animals present include black bear and mountain lion. Several years ago, the operator entered into a cooperative agreement with the surface owner for extensive monitoring of the big game herds, in order to determine the effects of mining on game populations, and to design appropriate mitigation efforts. Subsequently, this monitoring has been expanded to include nongame animals and fish in order to obtain an overall picture of the wildlife ecology of the area. The operator has collected extensive telemetry and mapping information from radio-collared big game animals, and has analyzed the quality of nearby habitats, presence or absence of suitable habitat for given species, animal distance from the operation, and wildlife's ability to adapt to mining. To date, these efforts indicate use by mule deer and elk of reclaimed areas adjacent to the active mining operation. Wildlife mitigation measures implemented at the mine comprise specifically designed techniques and alternate reclamation practices to improve habitat components beneficial to wildlife. The site-specific designs include: 1) construction of rock piles placed randomly within reclaimed areas as shelter and escape cover for small animals and as perch sites for birds and raptors; 2) formation of brush piles to provide habitat analogous to rock piles; 3) fencing of the permit area to exclude livestock that could compete for forage, trample riparian vegetation, and compact streamside soils; 4) replacement of tree-cavity nesting habitat (nest boxes) for kestrels; 5) fertilization of offsite habitats to improve forage production for big game; 6) education of mine personnel about the effect of wildlife harassment; and 7) introduction of stocked fish in mine-area ponds as a "barometer" of water quality and to provide prey for fish-eating predators. Alternate reclamation practices involve: 1) leaving a short stable highwall that resembles natural rock outcrops and bluffs and adds topographic diversity, 2) redistribution of soils to place thin rocky soils on slopes and thicker soils on ridgetops and valley bottoms to encourage plant diversity, 3) targeting earlier successional plant communities in the seed mix to promote habitat diversity and forage production, and 4) reestablishment of shrubs and trees in configurations beneficial to wildlife, such as travel lanes and mixing of types for edge effects.

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[1] See case study mine G in reference 1.

habitat. In addition, the selected plants must be grouped and distributed in a manner that optimizes edge effect, cover, and other benefits to wildlife.

Operators also must avoid disturbing, enhance where practicable, restore, or replace wetlands and vegetation along rivers, streams, and ponds, as well as other habitats of unusually high value for fish and wildlife (e.g., cliffs supporting raptor nests, wintering and nursery areas, breeding areas, etc.). At some mines, this may involve manipulating the postmining topography to obtain landscape diversity (see ch. 8), or recreating special wildlife habitat areas such as sage grouse strutting grounds (see box 3-Q, below), woody draws (box 3-O), and wetlands (box 3-G). For other land uses, however, mitigation efforts often are limited to measures such as planting groups of trees or shrubs to break up blocks of land and to diversify habitat types for birds and other animals. Rockpiles and other surface features beneficial to wildlife often are replaced postmining.

Avoidance techniques **range from disallowing mining to preserving small patches of important habitat, to maintaining or establishing visual barriers or buffer zones between mining operations and sensitive wildlife habitat.** Avoidance measures also can be temporal—for example, prohibiting blasting or mining near breeding areas during the breeding season. In areas where habitat removal is imminent, temporal avoidance only postpones removal during important wildlife seasonal activities, and therefore the benefits usually are short-term unless the habitat is restored following mining. Avoidance requirements may be imposed prior to leasing as a result of application of the unsuitability criteria (see ch. 4), or during permitting based on the wildlife impact assessments included in the permit application package.

Avoidance of important habitats or patches of vegetation can be important for maintaining natural sources of wildlife and vegetation for reinvasion into reclaimed areas. However, the importance of these areas as wildlife habitat during mining may be limited if the areas are small or isolated by large tracts of disturbed land. Moreover, operational, cost, and full coal recovery considerations often limit an operator's ability to avoid important habitats.

As experience is gained with wildlife responses to mining in the West, less emphasis has been placed on avoidance measures. For example, during the late 1970s and early 1980s, wildlife biologists believed that all eagles were extremely sensitive to human activity, especially during breeding or fledging seasons. As a result, it was standard practice for coal leasing and permitting agencies to require an undisturbed buffer zone around active eagle nests. Recent research has shown, however, that some eagles may be much more tolerant of nearby disturbances from mining than expected, and that in some cases nests can be moved without adverse impacts on the eagle population (see box 3-P; see also ch. 9, box 9-A).

***Operational mitigation techniques* may involve the education or regulation of mine personnel, as well as modifications in mine operations or mine plan structures designed to reduce the potential for adverse impacts.** Specific techniques include lowering speed limits on access and haul roads to reduce the potential for roadkills, designing and locating roads and other structures so as not to interfere with wildlife movement, conducting employee wildlife awareness programs, or making powerlines raptor-safe (see fig. 3-11).

***Offsite enhancement* measures usually focus on modifying habitats to increase their value to targeted species, or constructing new habitats offsite to replace those to be disturbed by mining (see box 3-Q), and are used to mitigate projected wildlife impacts resulting from disturbance or removal of mine-area habitats.** Providing alternate raptor nest sites (e.g., rockpiles), improving surface-water resources, eliminating live-

Box 3-O.—Reestablishment of Woody Draws[1]

Reestablishment of woody draws involves deciduous tree and shrub communities in both Montana and North Dakota. One mine in North Dakota is reestablishing woody draws with subcategories of mixed deciduous woodland, tall shrubland, and low shrubland (see table 3-4). Because these species require abundant soil moisture, the restoration process at this mine begins with the creation of topographic features to retain moisture, especially concave sites with north or east exposures. Species are clustered on those parts of the drainage with the most favorable moisture regime. The special handling of soils to return those with proper water-holding qualities is practiced sometimes, but is difficult in North Dakota where regulations require return of topsoil to the surface owner. Bareroot stock has been grown in a nursery from local seeds when feasible. The mine installs approximately 2,700 transplants per acre with furrow-type planters. Heavy mulch (5 tons/acre of sloughgrass hay or wood chips) is used to control herbaceous competition and minimize soil erosion.

---

[1] See case study mine B in reference 1 and ND-1 in reference 13.

Table 3-4.—Plant Species and Performance Standards for Woody Draw Restoration at a Mine in North Dakota

Species planted	Plants/ acre	Performance standards
Mixed deciduous woodlands:		
Willow	135	3,745 plants/acre of which 1,315 are trees and 2,430 are shrubs; all species planted must be present; for each species, at least 50% of the number planted must be present
Boxelder	270	
Green ash	810	
Cottonwood	405	
Burr oak	135	
Aspen	135	
Native plum	270	
Chokecherry	270	
Serviceberry	135	
Round-leaved hawthorn	135	
Tall shrub type:		
Native plum	675	8,100 shrub stems/ acre; all species planted must be present; for each species, at least 50% of the number planted must be present
Silver buffaloberry	135	
Serviceberry	540	
Chokecherry	540	
Round-leaved hawthorn	540	
Red osier dogwood	135	
Bristly gooseberry	135	
Low shrub type:		
Silverberry	540	10,800 stems/acre; all species planted must be present; for each species, at least 50% of the number planted must be present
Western wild rose	1,080	
snowberry	1,080	

SOURCE: Western Resource Development Corp. and Jane Bunin, "Revegetation Technology and Issues at Western Surface Coal Mines," contractor report to OTA, September 1985.

stock grazing, and thinning of overly dense shrub stands are examples of offsite enhancement techniques. In other instances, these practices may be undertaken to protect newly established vegetation from wildlife. Surface ownership of, and land use practices on, adjacent areas are the primary factors (other than cost) determining the extent to which offsite enhancement measures are implemented.

Box 3-P.—Relocating Golden Eagle Nests[1]

Wildlife studies at a mine in southern Wyoming documented at least four active golden eagle nests in mine highwalls scheduled to be reclaimed. Nearby mining and reclamation activities apparently had no adverse effects on the eagle pairs, and all four nests successfully fledged young. In 1982, the operator, FWS, the Wyoming Department of Game and Fish, and the Wyoming regulatory authority initiated a cooperative effort to formulate the best technique for relocating two of the highwall-nesting golden eagle pairs. Artificial nesting platforms were built near the active nests, and fledglings were moved from the nests to the platforms to lure the adults to the new nest sites. As additional active eagle nests were established on highwalls in subsequent years, nest relocations have been attempted by moving young to nearby natural rimrock areas or to artificially established boulder nest sites. Most relocations were successful and a monitoring program was instituted to evaluate continued nesting on the platforms.

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[1] See case study mine D in reference 1.

Box 3-Q.—Creation of a Sage Grouse Strutting Ground[1]

At a mine in southeastern Montana, the path of future mining was expected to disturb a known sage grouse strutting ground (lek). Baseline studies were performed to analyze the sage-grouse habitats and fidelity to the breeding ground. A new sage grouse strutting ground was created offsite by clearing an area on relatively high ground that was surrounded by suitable sage grouse habitat—primarily sagebrush 5 to 30 inches high with an average cover of 14 to 25 percent, intermixed with forbs. Decoys and tapes of male sage grouse "booming" were used to induce birds to use the relocated strutting ground. Experimental studies strongly indicate successful transfer of fidelity from the old ground to the new ground. Documented decreases of breeding activity at the old lek correlate highly with increases at the new offsite area.

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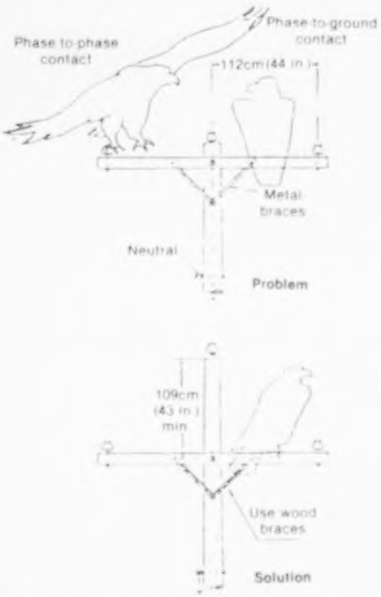
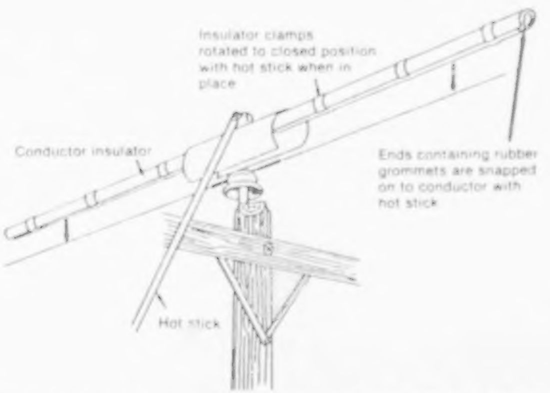
[1] See case study mine C in reference 1.

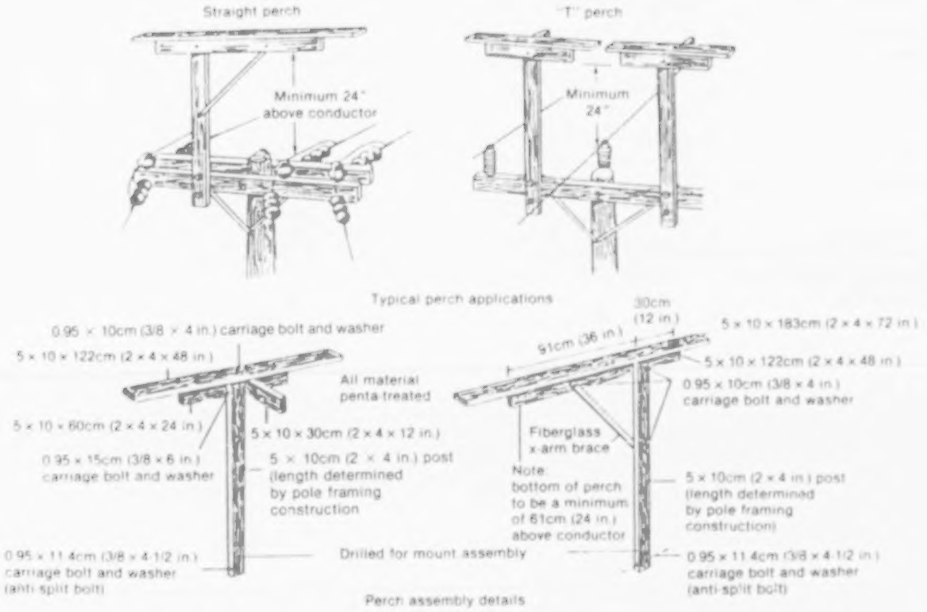
Figure 3-11.—Designs for Raptor-Safe Powerlines


Phase to phase contact
Phase to ground contact
112cm (44 in.)
Metal braces
Neutral
Problem
109cm (43 in.) min
Use wood braces
Solution

Vertical separation of the center and two outside conductors precludes the electrocution hazard on one type of pole


Insulator clamps rotated to closed position with hot stick when in place
Conductor insulator
Ends containing rubber grommets are snapped on to conductor with hot stick
Hot stick

Protective conductor insulation cover for installation on poles used by raptors as an alternative to pole reconstruction


Straight perch
Minimum 24" above conductor
"T" perch
Minimum 24"
Typical perch applications
0.95 × 10cm (3/8 × 4 in.) carriage bolt and washer
5 × 10 × 122cm (2 × 4 × 48 in.)
All material penta-treated
5 × 10 × 60cm (2 × 4 × 24 in.)
5 × 10 × 30cm (2 × 4 × 12 in.)
0.95 × 15cm (3/8 × 6 in.) carriage bolt and washer
5 × 10cm (2 × 4 in.) post (length determined by pole framing construction
0.95 × 11.4cm (3/8 × 4-1/2 in.) carriage bolt and washer (anti-split bolt)
Drilled for mount assembly
30cm (12 in.)
91cm (36 in.)
5 × 10 × 183cm (2 × 4 × 72 in.)
5 × 10 × 122cm (2 × 4 × 48 in.)
0.95 × 10cm (3/8 × 4 in.) carriage bolt and washer
Fiberglass x-arm brace
Note: bottom of perch to be a minimum of 61cm (24 in.) above conductor
5 × 10cm (2 × 4 in.) post (length determined by pole framing construction)
0.95 × 11.4cm (3/8 × 4-1/2 in.) carriage bolt and washer (anti-split bolt)
Perch assembly details

Artificial perches mounted above existing poles as an alternative to pole modification (suitable primarily for treeless areas) and perch assembly details.

SOURCE: U.S. Department of the Interior, Fish and Wildlife Service, *Practices for Protecting and Enhancing Fish and Wildlife on Coal Surface-Mined Land.*

Photo credit: Colowyo Coal Co.

Thinning dense shrub stands on an undisturbed portion of the mine site during the winter stimulates new spring growth attractive to browsers such as elk, thus reducing wildlife use of revegetated areas.

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Chapter 4

Western Surface Mine Regulation

INTRODUCTION

Western surface coal mining is a highly regulated activity, especially when the surface or coal is federally owned. From a company's exploration for coal reserves, through securing the rights to develop those reserves, to mining and reclamation, the company must obtain a wide variety of permits and must ensure that its activities comply with the conditions of those permits as well as with a host of other Federal, State, and local laws and regulations. Moreover, many of the Federal laws governing coal development provide for State permitting programs consistent with the Federal program, resulting in permit application review at both the Federal and State level. The scope of Federal agency involvement in this process is much broader in the Western United States than in other parts of the country because of the Federal Government's extensive ownership of both surface and mineral resources.

At each step in Western coal development and its regulation, existing data are analyzed in increasing detail and supplemented by more directed data-gathering efforts. This is possible because the amount of land being evaluated at each successive stage in the process becomes progressively smaller as the land moves closer to leasing and development. Prior to development, the ultimate level of detail in data collection and analysis is in support of a mining and reclamation plan and permit application under the Surface Mining Control and Reclamation Act of 1977 (SMCRA). After development, emphasis shifts to the gathering and analysis of monitoring data to ensure compliance with the plan and permit, and to demonstrate reclamation success.

This chapter describes the Federal and State regulatory process for Western coal development, from leasing through reclamation and bond release (see table 4-1). In describing that process, the chapter focuses on data and analysis requirements as an introduction to chapters 5 and 6, and on performance and design standards as an introduction to chapters 7 and 8. While the greatest emphasis is placed on the coal leasing program and on the provisions of SMCRA, other related programs are described, including the National Environmental Policy Act (NEPA), and the Clean Air and Water Acts. A wide range of other Federal laws that could affect surface coal mining and reclamation in the West are listed at the end of the section on permitting and regulation; State laws are summarized in tables 4-3 through 4-7 at the end of the chapter.

THE COAL LEASING PROGRAM[1]

Because the Federal Government owns 50 to 60 percent of the coal reserves in the six major Federal coal States, much Western coal must be leased from the Bureau of Land Management (BLM; or, in a few cases, the U.S. Forest Service) before it can be mined. Of the 76 active surface coal mines in the five State study region in 1983, 52 (roughly 70 percent) incorporated Federal coal. Under the Federal Coal Leasing Amendments Act of 1976 (FCLAA), BLM holds competitive lease sales for new production tracts on a schedule and in amounts determined by the market demand for coal. Companies also may request lease sales to be scheduled for bypass tracts (a lease needed to prevent leaving "islands" of unmined coal) and maintenance tracts (needed to continue operations at an existing mine).

A company begins planning for coal leasing long before the sale actually is held by gathering data about the coal and other resources in a particular area under an exploration permit. Coal resource data gathered under such a permit is pro-

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[1] Unless otherwise noted, the text in this section is adapted from reference 3.

Table 4-1.—Planning and Regulation of Western Federal Coal Development

Bureau of Land Management[a]	OSM/Regulatory authority	Coal company
Leasing:		
Permit and supervise coal exploration on Federal lands Evaluate coal resources Planning for management of all resources based on inhouse and published data Apply unsuitability criteria Planning for coal lease sale based on above plus some field data Prepare regional lease sale EIS Prepare lease stipulations Determine lease bond Hold lease sale		Collect and analyze coal resource data Prepare formal expressions of interest for specific lease tracts Prepare bids for lease tracts
Permitting:		
Delineation of permit area Responsible for all nonlessee activity on leased land prior to onset of mining Approve designation of postmining land use in permit application package Review permit application package for efficient extraction of the mineral resource, consistency with the resource area management plan, and compliance with lease stipulations Concur in approval of permit application and issuance of permit	Delineation of permit area Review permit application package and make recommendations on mining and reclamation plan Prepare EA and/or EIS for permit Determine performance bond Prepare permit stipulations Issue permit	Compile existing data on all mineral and ecological resources on mine site from inhouse, BLM, USGS, SCS, FWS, etc. sources Formulate first approximation of mining and reclamation plan Complete baseline data collection on all aspects of mine site Analyze data to predict impacts of mining and demonstrate success of proposed reclamation Prepare permit application package Collect and analyze additional data and revise permit application package, if necessary
Mining:		
Oversee production of the coal resource Oversee uses of Federal surface outside the permit area including rights-of-way and activities ancillary to mining	Conduct inspections of the mine site to ensure compliance with the permit Review monitoring data submitted in accordance with the permit to ensure compliance Act to correct violations, if necessary Enforce and collect penalties for violations, if necessary Review and approve applications for permit modifications Review and approve applications for permit renewals	Collect high-intensity geologic and hydrologic data as pit moves across mine site Collect monitoring data on hydrologic and wildlife impacts as mining proceeds Continually refine mining and reclamation plan based on new data collected Prepare applications for modifications to permit, if necessary Prepare application package for permit renewal every 5 years, if not initially issued for life-of-mine Reclaim mined areas as contemporaneously as possible with mining Monitor revegetation and hydrologic restoration
Evaluation of reclamation success:		
Inspect for compliance with any special requirements for protection of surface resources and postmining land use Concur in reclamation bond release Release lease bond	Develop criteria for evaluating success of reclamation (if not specified in the permit) for all three phases of bond release Review applications for bond release and conduct onsite inspections and evaluations Release reclamation bond	After backfilling and grading, prepare application for Phase I bond release (up to 60%) After surface stabilization and initial revegetation, prepare application for Phase II bond release (15 to 25%) Ten years after last seeding, fertilizing, irrigating, or other work, prepare application for final bond release

[a] Or other surface management agency (e.g., U.S. Forest Service).

SOURCE: Office of Technology Assessment.

prietary, but must be made available to BLM on a confidential basis in support of an expression of interest in a particular lease tract (see below) to assist BLM in identifying areas with high coal development potential that should be considered for coal leasing. Data on noncoal resources may be gathered during exploration to enable the company to estimate the potential costs of development and exploration; such data also are proprietary but do not have to be shared with DOI preleasing. BLM and the companies also may use coal resource data collected by Federal agencies in earlier minerals surveys (e.g, by the U.S. Geological Survey or the Bureau of Mines).

Most of the required preleasing data collection and analysis is carried out by BLM field personnel consistent with section 3(a) of FCLAA, which requires that lands considered for leasing shall have been included in a comprehensive land use plan and that lease sales be compatible with that plan. The comprehensive land use planning procedures developed by the Department of the Interior (DOI) to implement section 3(a) of FCLAA are based on the mandates in the Federal Land Policy and Management Act of 1976 (FLPMA).

FLPMA requires a multidisciplinary and comprehensive Federal land use planning process that maintains an up-to-date inventory of public land resources, giving priority to the designation and protection of areas of critical environmental concern (ACECs); projects *all* potential future uses of public lands and resources (not just coal development); and identifies opportunities for the development or conservation of particular resources, considering the relative scarcity of the resource values involved and the availability of alternative means for realizing those values. This land use planning is to be guided by the principles of multiple use of lands and resources, sustained yield of renewable resources, and conservation of depletable resources. The land use plan must protect the quality of scenic, historical, environmental, air and water, and archeological values, including ACECs; preserve certain lands in their natural conditions; provide food and habitat for fish and wildlife and domestic animals; and provide for outdoor recreation and human occupancy and use (18). Planning activities must be coordinated with those of other Federal, State, and local agencies; and must afford the public adequate opportunity to comment on the management of public lands.

Based on these general planning mandates, DOI structured the Federal coal leasing program around an initial comprehensive land use planning process which applies to all Federal lands and all resources on those lands, followed by "activity" planning for the development of specific resources or uses, such as coal leasing (see fig. 4-1). As noted above, a decision to offer a tract for lease is made in the context of a "tiered" system of planning and analysis, in which the level of analytical detail increases over time, while the size of the area being evaluated decreases. Thus, early in the process when few data are available, large land areas are classified according to their relative value for development of all possible resources. Lands that are identified as potentially suitable for coal leasing at this stage are then subjected to increasingly detailed analyses as the lands move closer to actual coal development, with the most comprehensive analyses occurring after leasing with the development of a mining and reclamation plan and permit application under SMCRA.

Land Use Planning

The principal objective of the land use planning process is to establish a multiple resource use management strategy for each of the "planning units" set up by BLM for the administration of public lands.[2] This is accomplished through identification of *all* potential land uses and or opportunities for the development of particular resources based on their relative values. Coal development is one possible land use, and, during land use planning, four screens are used to identify the acceptability of public lands for further consideration for leasing. The screens focus on coal development potential, the environmental acceptability of lands for mining, multiple use management, and surface owner preferences

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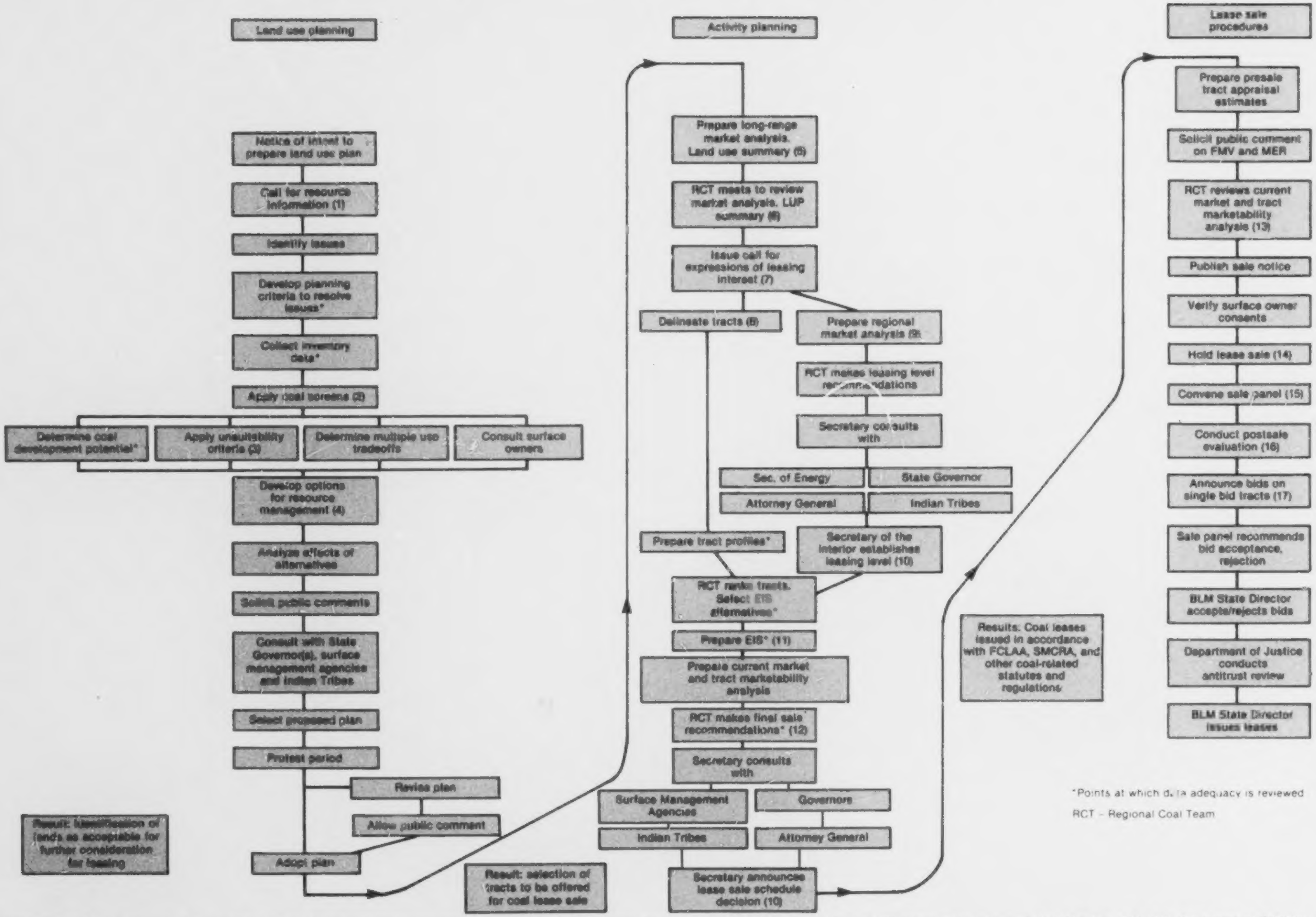
[2] It should be noted that many of the land use planning requirements described below also apply to other agencies that manage Federal lands overlying coal deposits (e.g., the U.S. Forest Service). The land use planning schedules and priorities within these agencies need to be coordinated closely with BLM's planning for lease sales.

Figure 4-1.—Proposed Coal Leasing Program Flowchart (Proposed Action)



Land use planning
Notice of intent to prepare land use plan
Call for resource information (1)
Identify issues
Develop planning criteria to resolve issues*
Collect inventory data*
Apply coal screens (2)
Determine coal development potential*
Apply unsuitability criteria (3)
Determine multiple use tradeoffs
Consult surface owners
Develop options for resource management (4)
Analyze effects of alternatives
Solicit public comments
Consult with State Governor(s), surface management agencies and Indian Tribes
Select proposed plan
Protest period
Revise plan
Allow public comment
Adopt plan
Result: Identification of lands as acceptable for further consideration for leasing
Activity planning
Prepare long-range market analysis. Land use summary (5)
RCT meets to review market analysis. LUP summary (6)
Issue call for expressions of leasing interest (7)
Delineate tracts (8)
Prepare regional market analysis (9)
RCT makes leasing level recommendations
Secretary consults with
Sec. of Energy
State Governor
Attorney General
Indian Tribes
Secretary of the Interior establishes leasing level (10)
Prepare tract profiles*
RCT ranks tracts. Select EIS alternatives*
Prepare EIS* (11)
Prepare current market and tract marketability analysis
RCT makes final sale recommendations* (12)
Secretary consults with
Surface Management Agencies
Governors
Indian Tribes
Attorney General
Secretary announces lease sale schedule decision (10)
Result: selection of tracts to be offered for coal lease sale
Results: Coal leases issued in accordance with FCLAA, SMCRA, and other coal-related statutes and regulations
Lease sale procedures
Prepare presale tract appraisal estimates
Solicit public comment on FMV and MER
RCT reviews current market and tract marketability analysis (13)
Publish sale notice
Verify surface owner consents
Hold lease sale (14)
Convene sale panel (15)
Conduct postsale evaluation (16)
Announce bids on single bid tracts (17)
Sale panel recommends bid acceptance, rejection
BLM State Director accepts/rejects bids
Department of Justice conducts antitrust review
BLM State Director issues leases

*Points at which data adequacy is reviewed

RCT - Regional Coal Team

SOURCE: U.S. Department of the Interior, Bureau of Land Management, *Federal Coal Management Program, Draft Environmental Impact Statement Supplement* (Washington, DC: U.S Government Printing Office, 1985).

about mining (where the Federal Government does not own the surface) (see box 4-A). Based on the results of the application of these screens, lands determined to be acceptable for further consideration for coal development are carried forward into activity planning for leasing.

For past lease sales, BLM applied these screens based on data available in-house as well as the published literature. This included earlier BLM land use planning documents, any environmental impact statements (EISs) prepared for earlier projects in the planning area, and the data from previous coal lease sales. These documents were updated through techniques such as areal mapping or limited field surveys. Under FLPMA, however, land use planning also must include a full EIS on resource management alternatives, and future planning efforts probably will involve additional field surveys to accumulate data at a sufficient level of detail to satisfy the requirements of NEPA.

Activity Planning and Lease Sales

After general resource planning for a management area is complete, subsequent planning focuses on a specific activity—in this case, coal leasing. Like land use planning, activity planning is predicated on a tiered system of increasingly detailed reviews of smaller and smaller areas until specific lease tracts are delineated. Activity planning culminates in a Secretarial decision on the tracts and tonnages to be offered for lease and the schedule for lease sales in that region.

Information from land use planning about areas' acceptability for mining, plus coal resource data from formal industry expressions of interest in particular areas, are used to develop initial draft leasing levels and to delineate tracts. After tract delineation, BLM field staff conduct a site-specific analysis (SSA) of the full range of environmental, social, economic, and other resource values on each tract. The SSAs provide the basis for detailed tract profiles, which are used to select combinations of tracts for analysis in the EIS for the lease sale (see below).

The SSA generates the greatest level of detail of information about a tract available to BLM before a lease sale. According to the programmatic EIS for leasing,

> . . . the information . . . must be sufficiently detailed so that the Department would be reasonably certain that the lease would be economically and environmentally acceptable, but in less detail than would be required of a lessee at the time a mining plan would be approved (5).

Following preparation of the tract profiles, the Regional Coal Team (RCT)[3] ranks tracts according to their acceptability for leasing after considering factors such as coal economics, impacts on the natural environment, and socioeconomic impacts (15). Tract rankings and SSAs do not necessarily affect tract delineation, although tract boundaries can be adjusted as the results of SSAs or tract rankings, or tracts may be dropped altogether at this stage.

The RCT uses these rankings to select combinations of tracts that meet the regional and alternative leasing levels. These must include a "preferred alternative" that optimizes the economic and resource benefits of leasing and minimizes the social and environmental costs. The environmental impacts of the leasing alternatives are then assessed in detail in an EIS for the lease sale. As a part of the tiered system, the data and analyses for the EIS expand on the information in the SSAs and tract profiles, but focus on particular combinations of tracts. Lease stipulations may be proposed in the EIS to protect environmentally sensitive areas (see box 4-B).

Following publication of the final EIS, written surface owner consent is confirmed, and the Secretary consults with the affected State Governors and the surface management agency prior to approving a combination of tracts and tonnages to meet a regional leasing level and establishing final dates for maintenance, bypass, and new production tract lease sales. Then DOI issues a notice of lease sale, performs the economic evaluation, and holds the sale.

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[3] The Regional Coal Team is a DOI/State organization made up of a representative of the Governor from each State in the region and the BLM State Director from each State involved. Each RCT is chaired by the BLM State Director from the State with the greatest direct concern.

Box 4-A.—The Land Use Planning Screens

The coal development screen categorizes lands according to their development potential (based on such factors as quality of coal, depth of seam, thickness of overburden, etc.). Information identifying major issues related to resource use and protection within a BLM planning unit is solicited from the coal industry, the public, other Federal agencies, State and local governments, and Indian tribes. This initial, general call for information is supplemented by a formal solicitation of industry "indications of interest" in leasing coal, and by industry information on coal resource development potential (11). Based on the responses to these requests for information, lands with no such potential are not considered further for leasing (12).

The acceptability of lands for mining is assessed based on 20 criteria (see table 4-2). Several of these criteria were mandated or suggested in SMCRA, several embody requirements under other Federal statutes which DOI chose to enforce through the unsuitability criteria review process (e.g., the Endangered Species Act), and some DOI selected on the basis of its judgment of their merits. Each of the criteria is applied to all coal lands identified as having development potential. If one or more criteria are found to apply in a particular area, exceptions and exemptions to the applicable criteria are analyzed to see if they pertain. If they do not, the land either will be considered unsuitable for further consideration for leasing, or mitigation requirements will be imposed through proposed lease stipulations.

The multiple resource use screen is intended to eliminate lands from further consideration for coal leasing if other resources on those lands are determined by BLM to be locally important or unique. The 10 management objectives are: 1) livestock grazing, 2) fish and wildlife development and utilization, 3)

Table 4-2.—The Unsuitability Criteria

1. Lands in the Federal land preservation system (e.g., National Parks, Wildlife Refuges, Trails, Wild and Scenic Rivers, Recreation Areas, Wilderness Areas);
2. Lands within rights-of-way or easements;
3. Lands within 100 ft of cemeteries and rights-of-way for public roads or within 300 ft of public and residential buildings;
4. Wilderness study areas, while under review for wilderness designation;
5. Class I scenic areas;
6. Lands used for scientific studies involving food or fiber production, natural resources, or technology demonstrations and experiments;
7. Publicly owned places on Federal lands which are listed on the National Register of Historic Places;
8. Lands designated as natural areas or as National Natural Landmarks;
9. Federally designated critical or essential habitat for threatened or endangered plant and animal species;
10. Lands containing habitat considered critical or essential for State-designated threatened or endangered plant and animal species;
11. Bald or golden eagle nests or sites, including appropriate buffer zones that consider habitat for prey species;
12. Bald and golden eagle roost and concentration areas used during migration and wintering;
13. Falcon cliff nesting sites and appropriate buffer zones that consider prey species' habitat;
14. High-priority habitat for migratory bird species of high Federal interest on a regional or national basis;
15. Essential habitat for resident fish and wildlife species of high interest to the State (e.g., active dancing and strutting grounds for sage grouse, sharp-tailed grouse, and prairie chicken; critical winter ranges for deer, antelope, and elk; and migration corridors for elk);
16. Lands in riverine, coastal and special flood plains (100-year recurrence);
17. Lands committed by the surface management agency to use as municipal watershed;
18. Natural resource waters identified in State water quality management plans and buffer zone of one-quarter mile from the outer edge of the far banks of the waters;
19. Alluvial valley floors (AVFs) considered important for agriculture, or land outside an AVF if mining would materially damage surface or underground water systems that supply the AVF; and
20. Lands deemed unsuitable by criteria proposed by a State and adopted by the Secretary of the Interior in rulemaking.

SOURCE: 43 CFR 3461.1.

industrial development, 4) mineral production, 5) human occupancy, 6) outdoor recreation, 7) timber production, 8) watershed protection, 9) wilderness preservation, and 10) preservation of public (unique or scarce) values (10). In general, a multiple-use trade-off is appropriate when one land use (e.g., mining) would absolutely preclude other valuable resource uses which are not covered by the 20 unsuitability criteria (13).

The surface owner preference screen requires that coal resources underlying privately owned surface not be considered for surface mining if a significant number of the surface owners object to leasing during the initial consultation with BLM. If underground mining is technically or economically infeasible, the land could still be considered for leasing, but it must be assigned a low priority compared with lands without surface owner conflicts (14). Final surface owner consents to leasing are not obtained until the end of activity planning.

SURFACE MINE PERMITTING AND REGULATION

Once a company has leased or purchased coal resources, it must prepare a comprehensive plan for the development and reclamation of the coal and obtain a variety of permits under Federal and State laws. The most extensive Federal regulations related to surface mining arise under the Surface Mining Control and Reclamation Act of 1977 (SMCRA), which establishes performance standards for mining and reclamation and requires mine operators to obtain a permit to ensure that those standards will be met. Other significant permitting and regulatory requirements arise under the Clean Air and Water Acts, and the National Environmental Policy Act. A listing of other Federal laws potentially affecting Western coal development may be found at the end of this section. Tables 4-3 through 4-7 at the end of the chapter list the State laws affecting surface mining.

SMCRA is implemented by the Office of Surface Mining (OSM), within the Department of the Interior, and by State agencies under approved regulatory programs consistent with SMCRA. Most Federal environmental legislation is implemented by the Environmental Protection Agency (EPA), with permitting and enforcement also delegated to States with approved programs. While the discussion in this section will emphasize the Federal regulatory programs, it should be kept in mind that in all of the Western States studied, the State regulatory authorities have the primary responsibility for surface mining permitting and enforcement, with OSM (and EPA) providing oversight and technical assistance.

Surface Mining Control and Reclamation Act

In regulating surface mining, the purposes of SMCRA are to:

- establish a nationwide program to deal with adverse impacts of surface mining;
- assure that the rights of surface landowners are fully protected from surface mining operations;
- assure that surface mining does not occur where reclamation is not technologically and economically feasible;
- assure that surface mining is conducted so as to protect the environment;
- assure that reclamation occurs as contemporaneously as possible with mining;
- assure vital coal supply is provided and strike a balance between environmental protection and agricultural productivity on one hand, and coal supply on the other;
- assist the States in developing and implementing a program to achieve the purposes of SMCRA;
- assure appropriate procedures for public participation in development, revisions, and enforcement of regulations, standards, reclamation plans, or programs established by the Secretary or any State under SMCRA; and
- provide for research and development, training of mining specialists, and State research centers (16).

Box 4-B.—Role of Lease Stipulations in Reclamation Planning and Permitting

The Bureau of Land Management frequently attaches stipulations to its coal leases to ensure protection of the surface environment during mining and reclamation. These stipulations commonly address mining impacts on wildlife, cultural and paleontological sites, surface water drainages, and other features of the premining environment. The frequency in use and the scope of lease stipulations have increased over time, particularly since the implementation of FCLAA and FLPMA. OTA's recent study, *Environmental Protection in the Federal Coal Leasing Program,* found that, in some instances, lease stipulations requiring data collection and analysis were used to defer decisions to the permitting stage that should have been made prior to leasing. In other cases, stipulations that specified particular reclamation methods or designs were viewed as usurping the regulatory authorities' decisionmaking power (3). Because of these findings, OTA was asked to try to determine, in this assessment, what the fate of such lease stipulations has been during the mine planning and permitting processes.

BLM must concur in the issuance of a permit for a leased tract. Where both Federal surface and Federal coal are involved—the most common case—both BLM's local Solid Minerals Branch and the Environmental Planning and Assistance Branch review a permit application to ensure efficient extraction of the mineral and environmental soundness and consistency with the applicable resource management plan. BLM's permit review procedures vary from State to State, but most often the surface compliance and environmental review is carried out at the resource area level.[1] The resource area manager circulates relevant sections of the application to staff specialists in the various areas of environmental concern. Most resource area offices have at least one, often more, of each of the following: range scientists, geologists, wildlife biologists, soil scientists, cultural resource specialists, archeologists, and foresters. After review by these professionals, BLM either concurs in the application or sends comments to OSM explaining problems it has found with the application.

OTA encountered several problems in determining how lease stipulations are treated in BLM's permit application review. First, none of the tracts leased since implementation of the new leasing program has completed the permitting process, so the fate of many recent stipulations has not yet been determined. BLM has, however, been imposing some types of environmental stipulations on coal leases for many years, plus a number of emergency and maintenance leases with stipulations have been issued since 1979 for extensions of existing operations that are now being mined.

Second, while the treatment of these two sets of stipulations during mine planning and permitting could offer some indication of the possible fate of more recent lease stipulations, OTA found that there is no clear "paper trail" marking the fate of lease stipulations. Neither BLM nor OSM makes a finding that lease stipulations have been complied with when they approve a reclamation plan. In fact, there is virtually no written documentation of BLM's environmental review of permit applications. The only way to discover what occurred during that review is to interview the BLM personnel involved. The turnover and rotation of BLM district and field office staff is so rapid, however, that many of the resource area managers, district managers, and division chiefs OTA spoke with had never reviewed a permit application. Environmental field staff, in particular, tended to be unfamiliar with the permit review process itself.

Moreover, there are few decision records or guidelines to aid BLM's environmental planning specialists in reviewing permit applications. The resource area management plan provides a record of decisions made on the unsuitability criteria for lease tracts, and the environmental impact statements on land use and leasing decisions document the environmental and socioeconomic concerns about coal development. However, these documents rarely provide the kind of detailed guidance needed to determine whether the mitigation measures in the mine plan are adequate to comply with lease stipulations.

Although general guidelines and criteria may not accommodate the unique features of each mine site, the absence of such guidelines or criteria is cause for concern because most BLM lease stipulations are so vague and general that permit applicants and regulatory authorities have great latitude in deciding how to satisfy stipulations. This is particularly true of the stipulations in older leases but also, to some extent, of the "boiler plate" stipulations such as the standard cultural and paleontological stipulations. Moreover, due to the high turnover in BLM field staff, the personnel reviewing a permit application usually are not the same as those who performed the preleasing analysis and developed the stipulations, and may have little or no prior experience with permit application review to guide them.

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[1] The exception among the five Western States seems to be Wyoming, where the district Solid Minerals Branch coordinates the entire permit review and the district environmental staff review the permit application. Only if they found large problems with an application would the district involve the resource area specialists (1).

Based on OTA's analysis of this process, it is clear that BLM's primary concern during the permit review is whether the mine plan will ensure full and efficient recovery of the Federal coal resources. In most instances, permit review is overseen by the Solid Minerals Branch and review of environmental considerations is secondary. Even within the environmental review, however, OTA found that lease stipulations are given little attention. Rather, that review primarily emphasizes compatibility with the designated post-mining land use and with the resource area management plan. Lease stipulations are often not even mentioned by BLM officials as a consideration.

BLM officials contacted by OTA emphasized that permitting and reclamation are the responsibilities of the States and OSM, and that the Bureau followed the State or OSM's lead in reclamation-related matters. On the other hand, State and OSM officials argue that ensuring compliance with lease stipulations is BLM's responsibility as the Federal surface management agency. Because stipulations are so vague and general in comparison to the extensive and detailed regulatory requirements for a mining and reclamation plan and permit application, OSM and State regulatory authorities rarely find the stipulations relevant to permitting.

To accomplish these objectives, Congress charged the Secretary of the Interior, acting through OSM, to develop and issue a Federal regulatory program to carry out the provisions of SMCRA, to assist the States technically and financially in developing programs that both meet the goals and minimum standards of SMCRA and reflect local requirements and conditions, to review and approve or disapprove State programs, and to enter into cooperative agreements with States with approved programs for the regulation of surface mining on Federal lands within the State.

The basic elements of the Federal regulatory program, as established in SMCRA, are performance and design standards that cover most aspects of surface mine reclamation, and the requirements for a detailed mining and reclamation plan to be submitted in support of a permit application. Special provision is made for experimental practices to encourage advances in mining and reclamation techniques. To ensure that the performance and design standards are met, and that a mine remains in compliance with the plan and permit, SMCRA requires regular monitoring and inspections of surface mining operations, with a range of enforcement penalties for violations. The act further requires permittees to file a performance bond in an amount sufficient to assure the completion of the reclamation plan if the work had to be completed by the regulatory authority (see ch. 7).

This section briefly reviews the general data and analysis requirements for the permit application package and for demonstrating that the performance standards and design standards will be met. The specific data requirements for the various disciplines—hydrology, soils and overburden, revegetation, and wildlife—are discussed in chapter 5, and the analytical techniques for predicting the impacts of mining and the success of reclamation in chapter 6. It should be noted that many of the provisions of the Federal regulatory program were ruled invalid in court decisions between July 1984 and July 1985, and it may be several years before the new rules are issued in their final form (see box 4-C). Where the court rulings substantially affect data or analysis requirements, this is noted in the text.

Permit Application Package: Legal and Regulatory Requirements

The permit application and the supporting mining and reclamation plan are the primary means

Box 4-C.—The Effects of the Flannery Decisions

In 1980, several organizations challenged, in Federal District Court, the original regulations implementing SMCRA which had been promulgated by Interior Secretary Andrus in 1979. While appeals to that decision were pending, the surface mining regulations were substantially revised by Secretary Watt, and the appeals court remanded the case to the District Court to hear any challenges to the new rules. The National Coal Association, and a number of environmental groups represented by the National Wildlife Federation, both came forward with challenges to various parts of the revised regulations (In Re: Permanent Surface Mining Regulation Litigation, Civil Action 79-1144). Between July 1984 and July 1985, the U.S. District Court issued three rounds of decisions and either struck down or remanded to DOI substantial portions of the revised Federal regulations.

In Round One, Judge Flannery struck down provisions that delegated most of the review responsibility for mining plans on Federal lands to the State regulatory authorities under cooperative agreements; and that excluded from regulatory authority jurisdiction and enforcement support facilities (e.g., coal cleaning, processing and preparation plants; rail spurs; mine offices) which are not directly connected to the mine site.

The Round Two decision sent regulations related to backfilling and grading, prime farmlands, alluvial valley floors (AVFs), bonding, subsidence, and roads back to DOI. On **backfilling and grading,** the court remanded regulations on cut-and-fill terraces and contemporaneous reclamation as not providing sufficient guidance to the States on minimum standards. For **alluvial valley floors,** Flannery struck down the regulations that define "farming" and "agricultural activities" as internally inconsistent, as well as those that defined the characteristics of AVFs that support the essential hydrologic functions as not providing sufficient guidance to the regulatory authorities. On **prime farmlands**, the court struck down an exception to the cropland restoration requirement for water bodies or impoundments created during mining as an impermissible variance from SMCRA, and an exception for support facilities because it did not specify the amount of land that can be exempted. On **bonding,** Flannery remanded rules that allowed a company to post a bond for an area smaller than that covered in a given permit term and that allowed bonds to cover specific phases of reclamation within the permit area. On **subsidence,** the court remanded to DOI the rule on redress of damage to surface structures. The court remanded the regulations on **roads** because they were issued without notice and opportunity for comment.

The Round Three Decisions were the most sweeping in terms of the scope of the regulations that were struck down or remanded to DOI. Rules related to the replacement of water supplies from aquifers adversely affected by surface mining and harmed by underground mining were struck down as inconsistent with SMCRA and State water laws. The court also upheld challenges to: the rules requiring probable hydrologic consequences analyses only for the duration of a permit—usually 5 years—as opposed to life-of-mine; the definition of "anticipated mining" for cumulative hydrologic impact assessments; the provision related to the stabilization of mining wastes; the shift from design to performance standards in the compaction of waste dams; rules governing highwalls and return to approximate original contour (AOC), including a general variance from the AOC requirement for steep slope mining, as well as variances for highwalls in remining operations and in underwater impoundments; definitions of cemeteries and public roads; regulations granting an exemption from mining in prohibited areas when the operator has made a substantial legal and financial commitment; rules that did not extend protection to privately owned places on the National Register; and the definition of when mining would be permitted in National Forests.

All of the rules struck down in the Flannery decisions must be rewritten by OSM, and must go through the notice and comment process for formal rulemaking. Even in an agency with little else on its agenda, this would be a formidable and time-consuming task. But OSM also must deal with a myriad of other problems related to its enforcement responsibilities and collection of penalties, ongoing reorganizations and new management, oversight of the State regulatory authorities, and the abandoned mine land reclamation program. Moreover, it is likely that the new regulations, when finally promulgated, also will be challenged in court. As a result, it may be several years before a stable permanent Federal regulatory program is in place. In the meantime, coal operators and State regulatory authorities face substantial uncertainty about the reclamation standards they must meet and enforce, and public confidence in the regulatory programs will be eroded.

of implementing SMCRA. Therefore, the data and analysis requirements are extensive. The application and plan are used to predict the impacts of mining and reclamation on all aspects of the environment, ensure that the performance standards will be met, establish standards for judging the success of reclamation, and provide the basis for determining postmining land uses. The SMCRA requirements for a permit application package, including the detailed mining and reclamation plan, essentially are divided into three segments: the baseline description of the mine site, the plan for recovery of the coal resource, and the reclamation plan and demonstration that reclamation is economically and technologically feasible.

The baseline description of the mine site provides the basis for estimating the impacts of mining on the natural and human environment, for comparing the premining and postmining conditions, and for establishing the postmining land use. Thus, the permit application package must include accurate maps or plans, to appropriate scale, clearly showing the land to be affected and its boundaries, as well as owners of all surface areas abutting the permit area and other on- and offsite features (for instance, gas and oil wells, buildings, parks, cemeteries, transmission lines, pipelines). Additional data requirements for environmental resources include the significant known archaeological sites as well as cultural and historic resources that are listed or eligible for listing on the National Register of Historic Places. The plan must specify how impacts on parks or historic places will be minimized.

The plan for recovery of the coal resource must describe: 1) the type and method of coal mining operation that exists or is proposed; 2) the anticipated annual and total production of coal by tonnage; 3) the engineering techniques proposed to be used in mining and reclamation, and a description of the major equipment; 4) the anticipated or actual starting and ending dates of each phase of the mining operation and the acreage affected; 5) a detailed estimated timetable for accomplishment of each major step in the reclamation plan; and 6) an estimate of the cost per acre of reclamation. Maps of the permit and adjacent areas also must show the existing and proposed facilities related to the mining and reclamation operations (e.g, coal loading, topsoil stockpiles, sedimentation ponds), and the plan must specify how these facilities will be built, maintained, and removed.

The demonstration of reclaimability must take into consideration the physical, climatological, and other characteristics of the site. Therefore, the regulatory authority may require that the permit application describe the climatological factors peculiar to the locality, including average seasonal precipitation, average direction and velocity of prevailing winds, and seasonal temperature ranges. The reclamation plan also must describe how the permittee plans to comply with the performance standards and with applicable air and water quality laws and regulations and any health and safety standards.

The postmining land use provisions of SMCRA require that all affected land be restored to a condition capable of supporting the uses that it could support prior to any mining, or higher or better uses of which there is a reasonable likelihood (see ch. 8). The reclamation plan must describe the premining condition of the land to be covered by the permit, including: 1) existing land uses; 2) the capability of the land prior to mining to support a variety of uses, giving consideration to soil and foundation characteristics, topography, and vegetative cover; and 3) the productivity of the land prior to mining, as well as the average yield of food, fiber, forage, or wood products under high levels of management.[4]

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[4] ''Capability'' and ''productivity'' are not defined in the Federal regulations implementing SMCRA. For the purposes of BLM management of Federal lands, ''capability'' is defined as ''the ability or potential of a unit of land to produce resources, supply goods and services or allow resource uses under a set of management practices at a given level of management intensity without permanently impairing the resource involved. Capability depends upon a fixed set of conditions which are relatively stable over time, including, but not limited to, climate, slope, landform, soils, and geology. Most land has an inherent capability to produce one or more resources, or goods and services, under natural conditions. Capability analyses shall permit identification of specific uses or management practices that cannot be allowed on specific land areas due to physical conditions.''

INTENTIONAL
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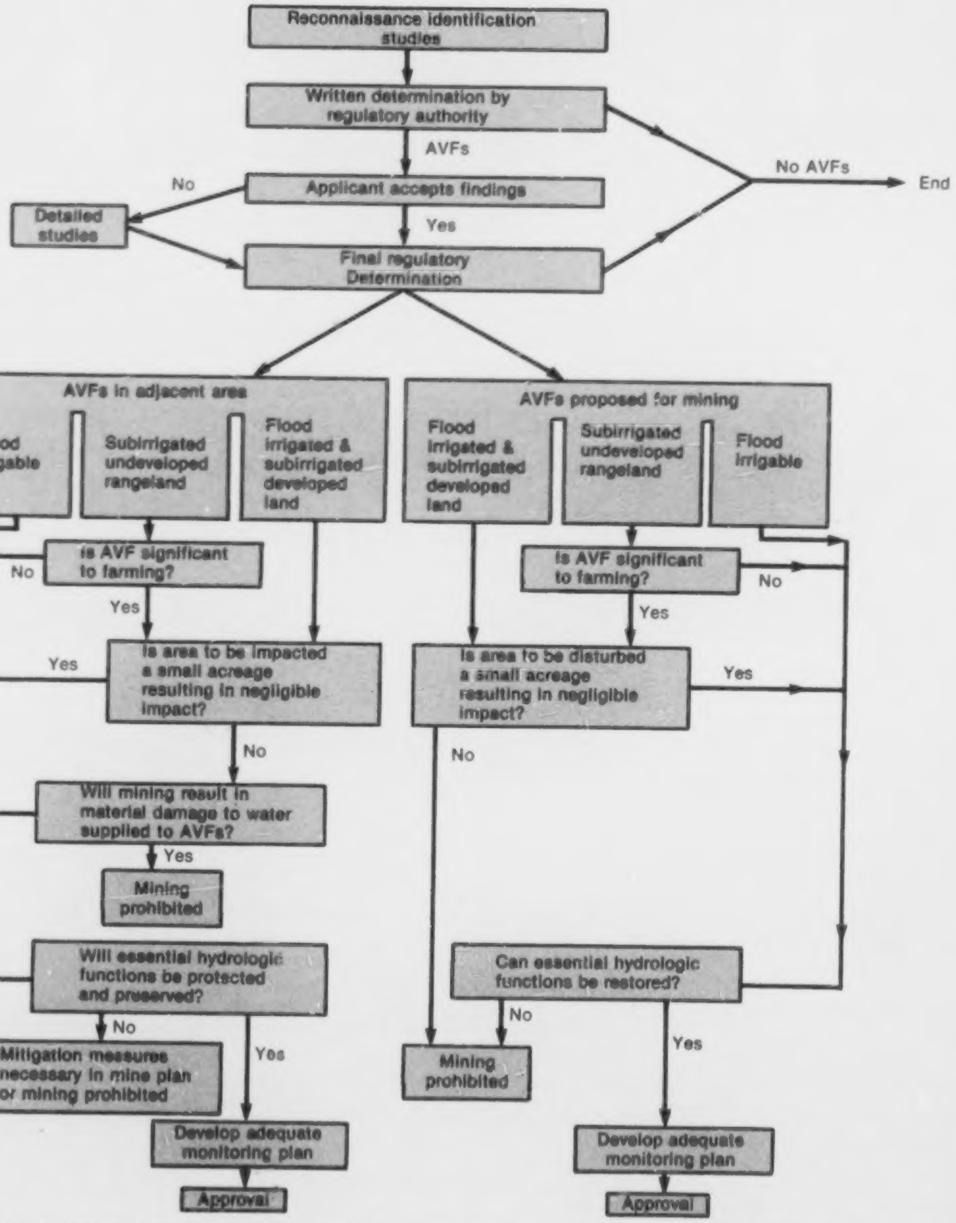
Figure 4-2.—Flowchart of Alluvial Valley Floor Regulatory Process


Reconnaissance identification studies
Written determination by regulatory authority
AVFs
No AVFs
End
No
Applicant accepts findings
Detailed studies
Yes
Final regulatory Determination
AVFs in adjacent area
Flood irrigable
Subirrigated undeveloped rangeland
Flood irrigated & subirrigated developed land
AVFs proposed for mining
Flood irrigated & subirrigated developed land
Subirrigated undeveloped rangeland
Flood irrigable
Is AVF significant to farming?
No
Yes
Is area to be impacted a small acreage resulting in negligible impact?
Yes
No
Will mining result in material damage to water supplied to AVFs?
Yes
Mining prohibited
Will essential hydrologic functions be protected and preserved?
No
Yes
Mitigation measures necessary in mine plan or mining prohibited
Develop adequate monitoring plan
Approval
Is AVF significant to farming?
No
Yes
Is area to be disturbed a small acreage resulting in negligible impact?
Yes
No
Can essential hydrologic functions be restored?
No
Yes
Mining prohibited
Develop adequate monitoring plan
Approval

SOURCE: U.S. Department of the Interior, Office of Surface Mining, *Annual Report of the Office of Surface Mining* (Washington, DC: U.S. Government Printing Office, 1983).

face mining operation during the 3 years prior to the date of the application, including the final resolution of such notices, and, if the applicant's ongoing operations are in violation of SMCRA, a declaration that the violation has been or is being corrected to the satisfaction of the regulatory authority.

Performance Standards

Section 515 of SMCRA establishes both general performance standards, and those specific to a particular discipline (e.g., hydrology), that cover virtually all aspects of surface mining. These are minimum standards, and the Federal or State regulatory programs may impose standards that are more stringent. SMCRA or the regulations often specify the mining and reclamation techniques that may be used to meet the performance standards, unless the operator demonstrates in the permit application that an alternative technique will be at least as effective. Such a demonstration may be expensive to prepare, however, especially given the risk that the alternative technique will not be permitted. Therefore, most operators rely on proven techniques unless there is a decided cost advantage to the alternative method due to site-specific considerations.

During the course of mining and reclamation, a company continually collects additional data and monitors the impacts of mining in order to demonstrate compliance with the permit and the performance standards. Thus, very detailed geologic data, as well as hydrologic and wildlife monitoring data are collected as the pit advances. The company refines the reclamation plan based on these data. If the term of the initial permit was

Photo credit: Jenifer Robison, OTA staff

As a mine pit advances, much more detailed geologic, hydrologic, and other data become available. A company continually refines its mining and reclamation plan based on these data, as well as on monitoring data from areas where mining is complete and reclamation has begun.

not for the life-of-the-mine, the additional data collection and analysis performed after the onset of mining also is used to support the application for permit renewal.

General Performance Standards.—SMCRA requires that all surface coal mining operations be conducted so as to maximize utilization and conservation of the fuel resource in order to avoid reaffecting the land in the future. Under the regulations related to coal recovery, surface mining activities also must use the best appropriate technology currently available[6] to maintain environmental integrity. In addition, operators must ensure that all reclamation efforts proceed in an environmentally sound manner and as contemporaneously as practicable with mining, and the regulatory authority may establish schedules that define contemporaneous reclamation.

Surface and Groundwater Systems.—All surface coal mining operations must be conducted so as to minimize disturbances to the prevailing hydrologic balance at the mine-site and in associated offsite areas, and to the quality and quantity of water in surface and groundwater systems both during and after mining and reclamation. Three basic hydrologic analyses are required under SMCRA to demonstrate that these standards will be met: 1) a determination of the probable hydrologic consequences (PHC) of mining and reclamation, on- and offsite, on the quantity and quality of surface and groundwater systems (including dissolved and suspended solids) under seasonal flow conditions; 2) an assessment of the probable cumulative hydrologic impacts (CHIA) of all anticipated mining in the area, particularly with regard to water availability; and 3) a hydrologic restoration plan that addresses the impacts predicted in the PHC determination and the CHIA, as well as the means to be used to meet the performance standards. In addition, the regulations impose specific design standards related to surface features such as siltation structures, diversions, impoundments, stream buffer zones, etc.

The PHC determination generally is based on baseline hydrologic, geologic, and other information, but an operator may use modeling techniques, interpolation, or other methods to generate data statistically representative of the site. The Federal regulations list four required sets of findings for the PHC determination. It must determine, first, whether adverse impacts may affect the hydrologic balance, and second, whether acid-, alkaline-, or toxic-forming[7] materials are present that could result in postmining surface or groundwater contamination. If adverse impacts or deleterious materials are found, supplemental data and analyses are needed to evaluate them and to plan remedial and reclamation activities (see chs. 5 and 6). Third, the PHC determination must address the potential for contamination, diminution, or interruption of surface or groundwater used for domestic, agricultural, industrial or other purposes. If any of these effects is predicted to occur, the reclamation plan must contain information on water availability and alternative water sources, including the suitability of such sources for the pre- and postmining land uses. Fourth, the PHC analysis must estimate the potential impacts on sediment yield from the disturbed area; acidity, total suspended solids (TSS), total dissolved solids (TDS), and other important water quality parameters of local impact; flooding or streamflow alteration; surface and groundwater availability; and other characteristics required by the regulatory authority. Standard methodologies for water quality sampling and analyses are listed in the Federal regulations.

The cumulative hydrologic impact assessment (CHIA) usually is performed by the regulatory authority based on hydrologic and geologic information provided (when available) by appropriate Federal or State agencies. If not available from such agencies, however, the permit applicant must collect sufficient data for the mine-site and surrounding areas so that the regulatory authority can perform this assessment, as the permit cannot be approved until this information is made available and incorporated into the application.[8] For purposes of permit approval, the CHIA must be sufficient to determine whether the proposed operation has been designed to prevent material damage to the hydrologic balance outside the permit area.

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[6] The Federal regulations define "best technology currently available" as "equipment, devices, systems, methods, or techniques which . . . are currently available anywhere as determined by the Director, even if they are not in routine use. The term includes, but is not limited to, construction practices, siting requirements, vegetative selection and planting requirements, animal stocking requirements, scheduling of activities . . . Within the constraints of the permanent program, the regulatory authority shall have the discretion to determine the best technology currently available on a case-by-case basis . . ."(9).

[7] "Toxic" is defined in the Federal regulations as "chemically or physically detrimental to biota"; it refers to the potential need for special handling of overburden strata and not to the disposal of toxic waste.

The hydrologic reclamation plan, including relevant maps and descriptions, indicates how the performance standards related to protection and restoration of water quality and the hydrologic balance will be met. This plan must be specific to local hydrologic conditions, and must describe the steps to be taken during mining and reclamation through bond release to minimize disturbances to the hydrologic balance; prevent material damage outside the permit area; meet applicable Federal and State water quality laws and regulations; and protect the rights of present water users or provide alternative sources of water where such protection cannot be assured. The plan must specifically address adverse hydrologic consequences identified in the PHC determination and the CHIA, and appropriate preventive and remedial measures.

The regulations specify that, in meeting the performance standards, mining and reclamation practices that minimize water pollution and changes in flow shall be used in preference to water treatment.

Overburden Handling.—Operators must backfill the pit, compact the backfilled overburden (where advisable to ensure stability or to prevent leaching of toxic materials), and grade it in order to restore the approximate original contour (AOC) of the land with all highwalls, spoil piles, and depressions eliminated. Small depressions may be left if they are needed in order to retain moisture, create and enhance wildlife habitat, or assist revegetation. Mines with very thick or very thin overburden may be exempted from the AOC requirement if the operator demonstrates that the thickness prevents attaining AOC.

Additional backfilling and grading requirements in SMCRA specify that operators stabilize and protect all surface areas, including spoil piles, to effectively control erosion and attendant air and water pollution, stabilize all waste piles in designated areas through construction in compacted layers, including the use of incombustible and impervious materials if necessary, and assure that the final contours of waste piles will be compatible with the natural surroundings.

Topsoil Handling.—After backfilling and grading of the overburden, the topsoil, or the best material available to support vegetation, must be restored to the mined area in a manner that will achieve an approximately uniform, stable thickness consistent with the approved postmining land use, contours, and surface water drainage systems. When the topsoil has to be stockpiled, the operator must protect it from wind and water erosion and keep it free of contamination by acid or toxic material by providing a temporary cover of quick growing plants (or other means). If the natural topsoil is too poor to sustain vegetation, or if other strata can be shown to be more suitable, these strata must be removed, segregated, and protected in the same manner. The data requirements for demonstrating the suitability of topsoil (or of selected overburden materials proposed to be used as a topsoil supplement or substitute) are discussed in chapter 5. The regulatory authority may require that the topsoil and subsoil be removed, stockpiled, and replaced separately ("two lifts") if necessary to meet the revegetation requirements. Two-lift topsoiling is required in North Dakota and Montana (sometimes Colorado), and practiced at several mines in other States in the study region (see chs. 3 and 8).

While the surface is exposed (i.e., prior to establishment of a permanent, stabilizing vegetative cover), erosion must be controlled. If rills and gullies form in regraded and topsoiled areas that disrupt either the postmining land use or revegetation, or that cause or contribute to violation of water quality standards, they must be filled, regraded, or otherwise stabilized, retopsoiled, and revegetated. The regulations also require, if necessary to promote successful revegetation, treatment (e.g., disking, ripping) of the regraded land, and application of nutrients and soil amendments.

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[8] If the annual production from the mine will be less than 100,000 tons, the determination of probable hydrologic consequences and the results of test borings or core samplings shall, upon written request of the operator, be performed by a qualified public or private laboratory designated and paid by the permit agency.

Revegetation.—SMCRA requires the operator to establish on regraded areas (and all other affected land) a diverse, effective, and permanent vegetative cover of the same seasonal variety native to the area, capable of self-regeneration and plant succession, and at least equal in extent of cover to the natural vegetation of the area.[9] The vegetative cover also must be capable of stabilizing the soil surface from erosion. The reclamation plan must describe existing vegetative types and plant communities with sufficient detail to predict the potential for reestablishing vegetation and to allow evaluation of the vegetation as important fish and wildlife habitat.

Specific provisions related to the timing of revegetation, and the use of mulching and other soil stabilizing practices are included in the regulations, as are standards for the success of revegetation (see ch. 7). Disturbed areas must be planted during the first normal period of favorable planting conditions—that planting time generally accepted locally for the type of plant materials used—after replacement of the topsoil (or other plant growth medium). Suitable mulch or other soil stabilization practices must be used on all areas that have been regraded and topsoiled, unless seasonal, soil, or slope factors make such stabilization unnecessary. In areas with less than 26 inches of annual precipitation (most of the study area), operators must assume responsibility for successful revegetation for 10 years after the last year of augmented seeding, fertilizing, irrigation, or other work (see ch. 7).

Wildlife.—Operators must, to the extent possible using the best technology currently available,[10] minimize disturbances and adverse impacts of mining and reclamation on fish, wildlife, and related environmental values, and achieve enhancement of such resources where practicable. Each permit application must include a detailed fish and wildlife plan that indicates how the performance standards will be met, including specific information on impact control measures, management techniques, and monitoring methods. If enhancement of wildlife resources and habitat is not practicable, this also must be demonstrated in the mining and reclamation plan. The Federal regulations add special provisions related to endangered species, bald and golden eagles, and wetlands and habitats of unusually high value, and they specify design standards for certain aspects of operations.

Operators must avoid disturbing, enhance where practicable, or restore wetlands and vegetation along rivers, streams, ponds, and lakes, as well as other habitats of unusually high value for fish and wildlife (e.g., cliffs supporting raptor nests, wintering and nursery areas, breeding areas, etc.; see ch. 3). Operators also must ensure that electric powerlines and other transmission facilities are designed and constructed to minimize electrocution hazards to raptors (fig. 3-11); that haul and access roads are located and operated so as to avoid or minimize impacts on important fish and wildlife species; and that fences, conveyers, and other potential barriers are designed to permit passage for large mammals.

No surface mining activity may be conducted that will jeopardize endangered or threatened species, or will destroy or adversely modify their designated critical habitats. Similarly, mining may not result in the unlawful taking of a bald or golden eagle, and its nest or eggs. If an operator becomes aware of endangered or threatened species or eagles within the permit area, he must report them promptly to the regulatory authority, which then consults with fish and wildlife agencies to identify whether, and under what conditions, mining may proceed (see ch. 3, box 3-P and related text).

Experimental Practices

SMCRA allows experimental departures from the environmental protection performance standards when the operator can demonstrate that such departures: 1) will encourage advances in mining and reclamation or will allow special postmining land uses; 2) are potentially more, or at least as, environmentally protective, during and after mining, as practices under the performance standards; 3) do not encompass a larger area or are not more numerous than necessary to determine the effectiveness and economic feasibility of the experimental practice; and 4) do not reduce the protection afforded public health and safety. Requests for experimental practices are subject to special public notice requirements and must be approved by the Director of OSM.

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[9] The regulatory authority may approve the use of introduced species only where desirable and necessary to achieve the approved postmining land use, although the use of such species may be approved on a temporary basis when necessary to achieve a quick-growing, stabilizing cover, and the permit and reclamation plan include measures to establish permanent native vegetation.

[10] In this context, "best technology currently available" is defined in the Federal regulations as "equipment, devices, systems, methods, or techniques which will minimize, to the extent possible, disturbances [of] and adverse impacts on fish, wildlife and related environmental values, and achieve enhancement of those resources where practicable."

An application for an experimental practice must describe the nature of the practice (including supporting maps, plans, and data); the performance standards for which variances are requested; and the duration of the practice. The application also must include a monitoring plan to ensure the collection, analysis, and reporting of sufficient data to enable the regulatory authority to evaluate the practice's effectiveness and to identify, at the earliest possible time, potential risks to the environment and public health and safety. As discussed in chapter 9, experimental practices are difficult to obtain and expensive to conduct. As a result, few companies propose them unless there are clear cost advantages to doing so.

Experimental practices are reviewed by the regulatory authority every 2½ years. After review, the regulatory authority may require reasonable modifications of the practice necessary to ensure that the activities fully protect the environment and public health and safety.

Monitoring Requirements

SMCRA specifies that the regulatory authority may require monitoring or other data collection relative to surface mining and reclamation, in general, and to disruption of aquifers, in particular, to assist in the development, administration, and enforcement of programs and permits. Special monitoring requirements relate to alluvial valley floors and to air quality control (see discussion of Clean Air Act, below). The regulatory authority is responsible for establishing standards and procedures for ensuring the reliability and validity of monitoring data collection and analysis.

Surface and groundwater monitoring plans are based on the results of the PHC determination, and on the analysis of all baseline hydrologic, geologic, and other data. Operators must monitor parameters affecting the suitability of surface and groundwater for pre- and postmining land uses as well as those related to compliance with the performance standards. The surface water monitoring plan also must address the effluent limitations established under the Clean Water Act (see below).

A special monitoring system is required to be installed, maintained, and operated on all AVFs during surface coal mining and reclamation operations and continued until all bonds are released. It must provide sufficient information to allow the regulatory authority to determine that the essential hydrologic functions of AVFs are being preserved outside the permit area or reestablished within the permit area throughout the mining and reclamation process; that farming on AVFs significant to agriculture is not being interrupted, discontinued, or precluded; and that the operation is not causing material damage to the quantity or quality of water in the surface or underground systems that supply protected AVFs. Monitoring must be conducted at adequate frequencies to indicate long-term trends that could affect compliance with the special AVF performance standards. The operator must make all monitoring data collected and analyses thereof available to the regulatory authority on a routine basis.

Inspections and Enforcement

SMCRA requires the regulatory authority to conduct regular inspections of surface mining and reclamation operations to ensure that they are in compliance with the performance standards and the mining and reclamation plan and permit. The regulatory authority must conduct an average of at least one partial inspection (onsite or aerial review of some of the permit conditions and program requirements) per month for active operations (as necessary for inactive), and an average of at least one complete onsite inspection every 3 months. Any potential violation observed during a partial inspection must be investigated in detail within 3 days, unless it poses an imminent danger to public health and safety or the environment, in which case it must be inspected immediately.

An immediate order to cease all mining and reclamation operations is issued for violations that create such an imminent danger, or when an operator has failed to abate a lesser violation within the prescribed period. A cessation order remains in effect until the violation is abated. Notices of violation (NOVs) are issued for conditions that do not create an imminent danger or harm. Civil monetary penalties are assessed for cessation orders and NOVs based on a "point" system that takes into account the operator's history of previous violations; the seriousness of the violation based on the probability of occurrence of the event which the violated standard was intended to prevent; the extent of potential or actual damage; the operator's degree of negligence; and good faith attempts to comply. The maximum penalty (70 points or more) is $5,000 per day. For operations that show a willful pattern of violations, the OSM Director may suspend or revoke the permit.

Clean Water Act

The Clean Water Act establishes national water quality goals to be achieved through State management plans that include water quality standards. These standards consist of the designated uses of the waters involved, including their use and value for public water supplies; propagation of fish and wildlife; recreational, agricultural, industrial, and other purposes; and navigation. In addition, the standards include water quality criteria for receiving waters based on these uses.

The water quality standards generally are to be achieved through effluent limitations on discharges from point sources. Effluent limitations are restrictions established by the State or EPA on quantities, rates, and concentrations of chemical, physical, biological, and other constituents that are discharged from point sources. Effluent limitations for surface coal mines regulate discharges of iron, manganese, and TSS, as well as the pH. In general, the act requires all categories of point sources to apply the best practicable control technology currently available in order to meet the effluent limitations.

Effluent limitations and water quality standards are implemented through State certification programs and through the National Pollutant Discharge Elimination System (NPDES). All point sources must obtain State certification that the discharge will not violate any effluent limitations, water quality standards, or New Source Performance Standards (NSPS). Under NPDES, a facility may be issued a permit for a discharge on the condition that the discharge will meet all applicable water quality requirements. NPDES permits are issued under EPA-approved State programs, or where a State program has not been approved, by EPA.

Effluent limitations have been established for mining operations, broken down into those applicable to acid and alkaline discharges. Under the Clean Water Act, mining operations must obtain NPDES permits and must use the best available control technology to comply with EPA or State effluent limitations. As discussed in chapter 8, sedimentation control ponds historically have been considered the best technology to control discharges of TSS to surface streams.

Clean Air Act

The Clean Air Act establishes a national system of air quality regulation in which EPA is responsible for developing Federal regulations and standards, and the States must implement plans consistent with the Federal program. The central feature of the Clean Air Act is the requirement that EPA promulgate National Ambient Air Quality Standards (NAAQS) in terms of ambient concentrations of pollutants. Primary standards are designed to protect human health, and secondary standards are intended to safeguard public welfare. EPA has established primary and secondary NAAQS for sulfur oxides, particulate matter, nitrogen dioxide, hydrocarbons, photochemical oxidants, carbon monoxide, ozone, and lead.

Every new major source of emissions is required to undergo a preconstruction review. Air quality control regions that are in violation of any

NAAQS or, at the opposite extreme, those where the air is already much cleaner than the standards require, are subject to more stringent requirements under the act with respect to the permitting of new point sources.

Air quality concerns regarding surface coal mining activities focus on fugitive dust and its effect on total suspended particulates. Thus far, air quality concerns have had only a minor effect on Western coal development. In some areas of the Powder River Coal Region of Wyoming fugitive dust emissions from surface mining have exceeded the NAAQS. Other Western coal operations are within pristine areas subject to the more stringent new source performance and prevention of significant deterioration standards. Mining operations in these areas have had to adopt better dust control measures or reduce the scope of their operations.

All Western surface mining activities with projected production exceeding 1 million tons per year (tpy) must include in their permit application package an air pollution control plan for fugitive dust. In addition, operators must devise a monitoring program that will provide sufficient data to demonstrate that the control practices are effective enough to comply with applicable Federal and State air quality standards.

National Environmental Policy Act

The National Environmental Policy Act of 1969 (NEPA) restructured Federal agency decisionmaking in favor of a systematic, interdisciplinary approach that would ensure that environmental amenities and values would receive appropriate consideration along with traditional economic and technical factors. NEPA was the first major environmental legislation approved by Congress, and it has remained the most far-reaching in scope.

NEPA requires all Federal agencies to include a detailed statement in every recommendation or report on proposals for legislation and other "major Federal actions significantly affecting the quality of the human environment" that describes:

- possible environmental impacts of the proposed Federal action,
- any adverse environmental effects that cannot be avoided should the proposed action be implemented,
- alternatives to the proposed action and their environmental impacts,
- the relationship between local short-term uses of man's environment and the maintenance and enhancement of long-term productivity as it applies to proposed Federal actions, and
- any irreversible and irretrievable commitments of resources that would result from implementation of the proposed action.

In order to determine whether a proposed action is "major" and will "significantly" affect the environment, Federal agencies prepare a preliminary environmental assessment (EA). The EA provides a brief examination and analysis of the proposed action and alternatives to it, a discussion of the need for the action, and an examination of potential environmental impacts. If an EA indicates that an action is not "major" or that it will not "significantly" affect the environment, the agency may publish a "finding of no significant impact" (FONSI), and then will not have to prepare a detailed EIS.

All coal-related activities that would have a significant impact on the environment and that need Federal authorization require a full environmental impact statement (EIS). This includes Federal land use planning and regional Federal coal lease sales, and, in some cases, permits to conduct surface mining operations under SMCRA.

Federal regulations may also require the preparation of an EIS when rulemaking is initiated by significant new circumstances or information relevant to environmental concerns. The initiation of the new Federal coal management program in 1979 was accompanied by a detailed programmatic EIS prepared in accordance with NEPA. That EIS was revised in 1985 to reflect changes proposed to be made in the leasing program, as well as more up-to-date coal resource and demand data (4).

Other Federal Legislation

In addition to the specific requirements of the Federal acts discussed above and the State programs implementing them, as well as the State legislation listed in tables 4-3 through 4-7, a wide range of other laws affect surface mining in the Western United States. These are listed below:

- **Act of September 28, 1976:** Provides for the regulation of mining activity within, and repeals the application of mining laws to, areas of the National Park System.
- **American Indian Religious Freedom Act of 1978:** Mitigates potential harm to American Indian religious sites.
- **Antiquities Act of 1906:** Regulates antiquities excavation and collection, including fossil remains.
- **Archaeological and Historical Preservation Act of 1974; Archaeological Salvage Act:** Provides for recovery of data from areas to be affected by Federal actions; provides for preservation of data, including relics and specimens, at every Federal construction project.
- **Bald Eagle Protection Act of 1969:** Protects bald and golden eagles.
- **Endangered Species Act of 1973:** Protects endangered and threatened species and critical habitat affected by Federal actions; requires prior consultation with Fish and Wildlife Service.
- **Fish and Wildlife Coordination Act of 1934:** Requires consultation about water resource development actions that might affect fish or associated wildlife resources.
- **Forest and Rangeland Resources Planning Act of 1974:** Provides for a comprehensive system of land and resource management planning for National Forest System lands.
- **Historic Preservation Act of 1966 (as amended):** Establishes systems of classifying properties on or eligible for inclusion on National Register of Historic Places; mandates Federal agency consultation with Advisory Council and State historic preservation officers.
- **Migratory Bird Treaty Act of 1918:** Requires enhancement of, and prevention of loss of, migratory bird habitats.
- **Mining and Minerals Policy Act of 1970:** Provides broad principles for mineral resource development.
- **Multiple Use-Sustained Yield Act of 1960:** Requires management of National Forests under principles of multiple use so as to produce a sustained yield of products and services.
- **National Forests Management Act of 1976:** Provides for a comprehensive system of land and resource management planning for National Forest System lands.
- **National Trails System Act:** Provides for establishment and protection of trails.
- **Noise Control Act of 1976:** Requires publication of information on limits of noise required to protect public health and welfare; preempts local control of railroad equipment and yard noise emissions.
- **Resource Conservation and Recovery Act:** Establishes guidelines for collection, transport, separation, recovery, and disposal of solid waste.
- **Safe Drinking Water Act of 1974:** Establishes mechanism for National Primary Drinking Water Standards.
- **Soil and Water Resources Conservation Act of 1977:** Requires appraisal by Secretary of Agriculture of information and expertise on conservation and use of soils, plants, woodlands, etc.
- **Wild and Scenic Rivers Act:** Provides for preservation of certain rivers or portions thereof in their natural state.
- **Wilderness Act of 1964:** Provides for establishment of wilderness reserves; requires preservation of wilderness areas in an unimpaired condition.

FEDERAL AGENCY RESPONSIBILITIES

A number of Federal agencies are involved in the administration of the laws and regulations described in this chapter. Most environmental legislation (e.g., Clean Air and Water Acts, Noise Control Act, Resource Conservation and Recovery Act, Safe Drinking Water Act) is administered by the Environmental Protection Agency. EPA also approves EISs prepared under NEPA, although the Council on Environmental Quality is responsible for promulgating regulations to implement NEPA. Federal land management agencies include the Bureau of Land Management and Fish and Wildlife Service within DOI, and the U.S. Forest Service within USDA. This section will focus on management responsibilities for Federal coal and surface mining regulation, which rest primarily with the Department of the Interior and its various agencies.

Until January 1982, DOI's functions and responsibilities for managing Federal coal were divided among the Office of Surface Mining, the U.S. Geological Survey (USGS), and the Bureau of Land Management. BLM was responsible for administering the provisions of FLPMA and FCLAA related to land use planning and the leasing of Federal coal. Regulation of coal development on Federal leases was shared by OSM and USGS, with OSM administering SMCRA, and the USGS determining coal reserves present on Federal lease tracts, developing coal resource economic evaluations for leases (recommendations for bonus bids and royalty rates), and preparing development and mineral resource recovery requirements for Federal leases. USGS also was responsible for overseeing coal exploration operations, and for reviewing mine plans and inspecting mines for compliance with resource, conservation, and recovery requirements (4).

In 1982, the Secretary of the Interior created, on an experimental basis, the Minerals Management Service (MMS), which assumed all major coal-related functions of the USGS Conservation Division. This organizational structure remained in place until late in 1982, when the Secretary consolidated the primary onshore mineral operations and leasing functions of the MMS into BLM, and made permanent the creation of the MMS. Thus, all aspects of leasing and production of coal resources are now within the purview of BLM, which, in addition to its overall responsibilities under FCLAA and FLPMA, enforces diligent development of leases, assures maximum economic recovery and conservation of mineral resources, and evaluates the economics of mining. BLM also must review permit applications and reclamation plans for proposed mines on federally leased coal for the resource considerations listed above, as well as for compliance with any lease stipulations for environmental protection or other purposes, and must concur in OSM's approval or disapproval of a permit. MMS retains responsibilities for auditing leases and collecting rents, royalties, and bonuses due the Federal Government on the sale and production of onshore minerals. (4)

Other DOI agencies with coal-related responsibilities are the Fish and Wildlife Service (FWS), USGS, Bureau of Mines, and Bureau of Reclamation. The FWS conducts surface mining studies to assess and predict the impacts of coal-related activities on fish, wildlife, and their habitats. FWS also monitors work related to impacts on wildlife in general and on endangered species in particular, and consults with BLM and OSM on fish and wildlife issues related to land use planning, coal leasing, and surface mine reclamation.

The Bureau of Mines conducts advanced coal mine health and safety research and demonstration projects on backfilling and subsidence. USGS provides technical assistance (including extensive databases; see ch. 5) for hydrologic studies, and administers a coal exploration program that provides maps, local and regional stratigraphy and correlation networks, and coal resource assessments (4).

The U.S. Forest Service is responsible for land use and activity planning on National Forest System lands. They apply the unsuitability criteria for coal leasing on these lands and, although BLM retains the responsibility for activity planning and for lease sales and administration, the Forest Service must consent to leases and may add terms and conditions to a lease to protect environmental values. The Forest Service also must concur with OSM on surface mining permits and reclamation plans for mining operations on National Forest lands (4).

STATE PROGRAMS FOR THE REGULATION OF SURFACE MINING AND RECLAMATION

While SMCRA established a nationwide program for regulating surface coal mining and reclamation, it also recognized that, because of the diversity in terrain, climate, biologic, chemical, and other physical conditions in areas subject to mining, the primary governmental responsibility for regulation should rest with the States. To assume exclusive jurisdiction over such regulation, States were required by SMCRA to develop and submit to DOI a State program which demonstrates that the State has the capability of carrying out the provisions of the act and achieving its objectives.

Under SMCRA, the minimum requirements for a State regulatory program are:

- a State law that provides for regulation in accordance with SMCRA, including effective implementation and enforcement of a permit system, and sanctions for violations of State laws, regulations, or permit conditions;
- rules and regulations consistent with those established by DOI under SMCRA;
- a State regulatory authority with sufficient administrative and technical personnel and funding to ensure the requirements of SMCRA can be met;
- a process for designation of areas as unsuitable for surface mining in accordance with SMCRA, provided that designation of Federal lands as unsuitable shall be performed exclusively by DOI after consultation with the States; and
- a process for coordinating the review and issuance of permits with any other State or Federal permit process applicable to proposed operations.

State laws or regulations may be more stringent than, or may relate to areas not covered by, SMCRA and the Federal regulations, but they may not be less stringent or less comprehensive. If a State fails to submit a program, submits one that is unacceptable, or fails to implement, enforce, or maintain an approved program, then DOI prepares and implements a Federal program for the State. In developing and implementing a Federal program for a State, DOI must consider the nature of that State's terrain, climate, biological, chemical, and other relevant local physical conditions. SMCRA also provides for Federal enforcement of a State program if the State is not enforcing it adequately.

Each of the five States in the study area has an approved regulatory program under SMCRA, as well as permitting authority under the Clean Air and Water Acts. Tables 4-3 through 4-7 list the State laws that may affect mining and reclamation. These laws are implemented through regulations and other interpretive documents such as guidelines, technical memoranda, field manuals, etc. Discussions of the State programs as they relate to baseline and monitoring data and analytical methods may be found in chapters 5 and 6. Detailed discussions of the State provisions related to surface and groundwater hydrology, soils and overburden, revegetation, and wildlife are included in the technical reports appended as volume 2 of this assessment.

Table 4-3.—Colorado Legislation Affecting Coal Development

Lead State agency	Legislation	Purpose	Major relevance
Department of Health:			
—Water Quality Control Commission	Water Quality Control Act	Establishes and administers water quality standards in State waters; requires NPDES permits	Requires site review and permitting for projects involving water, sewage, and waste disposal; establishes critera for erosion control dams
—Air Pollution Control Commission	Air Pollution Control Act	Establishes and administers air quality standards	Requires mines to use dust preventive measures in all mining procedures, including construction
State Land Use Commission	Land Use Act of 1974	Protects the utility, value, and future of all lands within the State, including the public domain and privately owned land	Local governments have the duty to identify, designate, and administer areas and activities of State interest, including mineral resource areas and mining
	Antiquities Act of 1973	Provides for the protection of historical, natural, or archeological values and for data recovery	Establishes areas containing or having significant historical, natural, or archeological resources as being of State interest; BLM must coordinate with State Historic Preservation Officer before approving mine plans or rights-of-way
Department of Natural Resources			
—Division of Mines	Mining Employees Safety Act	Provides for mine safety	Monitors mine safety practices
—Mined Land Reclamation Board	Mined Land Reclamation Act of 1976	Provides for the reclamation of land subjected to surface disturbance by mining; to conserve natural resources; protect wildlife and aquatic resources; and establish recreation, home, and industrial sites to protect and perpetuate the taxable value of property	Mine operation must obtain a permit, based on a plan of operations that includes a reclamation section; Board must hold public hearings and the applicable county must approve permit issuance
	Mined Land Reclamation Act of 1979	Mitigates impacts, assures reclamation, perpetuates existing regulations, and ensures that CO can carry out the purposes of SMCRA	Provides strict timeframe for issuing permits; permit requirements and performance standards similar to SMCRA; apply to surface operations and surface impacts incident to underground coal mines

SOURCE: U.S. Department of the Interior, Bureau of Land Management, *Federal Coal Management Program, Draft Environmental Impact Statement Supplement* (Washington, DC: U.S. Government Printing Office, 1985).

Table 4-4.—Montana Legislation Affecting Coal Development

Lead State agency	Legislation	Purpose	Major relevance
Department of Natural Resources and Conservation	Major Facility Siting Act	Provides for review and regulation of major facilities	Grants authority to require and review long range planning by certain utilities, to give approval to generation and conversion plant sites and associated facilities, and to require preconstruction certification of such facilities
Environmental Quality Council	Environmental Policy Act	To promote efforts to prevent or eliminate damage to the environment, to enrich the understanding of the ecological systems and natural resources important to the State	Requires EIS for all coal mine permit applications
Department of Health and Environmental Sciences	Water Pollution Control Law Solid Waste Management Act Clean Air Act	Protect the environment and reduce pollution	Establish standards and minimum amounts of deviation of pollutant substances
Department of State Lands	Strip and Underground Mine Reclamation Act	Protects resources and the environment	Detailed standards for the method of mining, blasting, subsidence, stabilization, water control, backfilling, grading, highwall reduction, topsoiling, and revegetation for lands affected by mining
	Strip Mined Coal Conservation Act	Prevents waste of marketable coal	
—Board of Land Commissioners	Antiquities Act	Protects historic, prehistoric, archeological, paleontological, scientific, or cultural sites and objects on State lands	Requires registration and protection of sites

SOURCE: U.S. Department of the Interior, Bureau of Land Management, *Federal Coal Management Program, Draft Environmental Impact Statement Supplement* (Washington, DC: U.S. Government Printing Office, 1985).

Table 4-5.—New Mexico Legislation Affecting Coal Development

Lead State agency	Legislation	Purpose	Major relevance
Environmental Improvement Division	Environmental Improvement Act of 1971	Establishes responsibilities for environmental management and consumer protection programs	Programs include water supply and pollution; liquid and solid wastes; air quality management; noise control; occupational health and safety
	Air Quality Control Act	Establishes and enforces regulations to prevent or abate air pollution	Requires submission of plans, specifications, and other information before issuing a permit for the building or modification of any new source of air pollution; requires that coal-handling machinery be equipped and haul roads be sprayed to prevent fugitive dust
Coal Surface Mining Commission	Surface Mining Act of 1979	Issues surface mining regulations	Requires permits for full range of protection on affected areas; reclamation plans and performance standards consistent with SMCRA
Energy and Minerals Department —Mining and Minerals Division	Surface Mining Act of 1979	Enforces surface mining regulations	Reviews and issues permits
Natural History Museum	Mining and Minerals Division Regulations	Provides for the recovery of paleontological data	Requires mines on State lands to notify the State Department of Finance and Administration, Office of Cultural Affairs, if important fossils are found
State Game Commission	Regulation 563	Protects State endangered species and subspecies	May make certain lands off limits to coal development
Historic Preservation Officer	Cultural Properties Act of 1969	Protects historical values	Regulates antiquities excavation and collection; requires data collection
Water Quality Control Commission	Water Quality Control Act	Protects surface and groundwater	Establishes and administers a comprehensive water quality program and develops a continuing planning process, adopts water quality standards, certifies permits, issues groundwater regulations for surface and underground mines
State Engineer	N.M. State Annotation 72-2-1 (1953 Compil.)	Provides for the general supervision, measurement, appropriation, and distribution of State waters	Reporting requirements for any person drilling to a depth of 10 feet or more and finding a water body or water-bearing stratum; permitting requirements for mine dewatering in a declared underground water basin

SOURCE: U.S. Department of the Interior, Bureau of Land Management, *Federal Coal Management Program, Draft Environmental Impact Statement Supplement* (Washington, DC: U.S. Government Printing Office, 1985).

Table 4-6.—North Dakota Legislation Affecting Coal Development

Lead State agency	Legislation	Purpose	Major relevance
Department of Health	Air Pollution Control Act	Establishes and administers air quality standards	Requires a permit for any plans to build, install, modify, or use any air contaminant source
	Solid Waste Management and Land Protection Act	Establishes solid waste disposal standards	Required to approve or disapprove permits for solid waste disposal plans; enforces ND NSPS
Environmental Health and Engineering Services	Water Pollution Control Act	Establishes and administers water quality standards	Facilities must meet standards
Environmental Control	Century Code (NDCC 23-25)	Protects air quality	Provides means of preventing significant deterioration of air quality from energy development; involves review of application for permit for new facilities and monitoring of operating facilities
	NDCC 23-29	Manages solid waste disposal	Requires permits for solid waste disposal facilities
	NDCC 61-28	Protects water quality	Requires permit to discharge mine water
Water Commission —State Engineer	NDCC 61-04	Administers water use	Permits must be secured for all water appropriations greater than 5,000 acre-feet for industrial uses
	NDCC 61-02, 61-16	Administers water use	Permits must be secured with the approval of the local water management district for building dikes or dams for water storage greater than 12.5 acre-feet
	NDCC 61-01	Administers water use	Permits must be obtained, with approval of local water management district, for drainage
State Geologist	NDCC 38-121	Provides for data recovery	Requires a permit for coal exploration and the filing of exploration data
Land Commission	NDCC 15-05	Protects and administers coal resources	Responsible for leasing State coal; coordinates with Federal leasing to prevent speculation
Public Service Commission	Surface Owners Protection Act	Protects surface owner rights	Requires approval by surface owners before permitting mining plans
	NDCC 38-14	Regulates surface mining	Requires a permit for coal surface mining and reclamation under regulatory program consistent with SMCRA
	Facility Siting Act	Regulates facility siting	Requires certification of site and corridor compatibility; requires route permit for transmission facility within the corridor

SOURCE: U.S. Department of the Interior, Bureau of Land Management, *Federal Coal Management Program, Draft Environmental Impact Statement Supplement* (Washington, DC: U.S. Government Printing Office, 1985).

Table 4-7.—Wyoming Legislation Affecting Coal Development

Lead State agency	Legislation	Purpose	Major relevance
Department of Environmental Quality —Land Quality Division —Water Quality Division —Air Quality Division	Environmental Quality Act of 1973 —Land quality regulations —Water quality standards —Ambient air quality regulations —Solid waste management regulations	Protects land, air, and water quality	Requires permits and licenses to mine upon approval of mining and reclamation plan under regulations consistent with SMCRA; permits for coal mines after approval of plans for monitoring and controlling air pollution; permits to build settling ponds and waste water systems; NPDES permits for mine discharge; construction fill permits and industrial waste facility permits for solid waste disposal for coal mines
Industrial Siting Administration	Industrial Development Information and Siting Act of 1975	Protects environment and socioeconomics	Requires extensive information and permit before powerplants and other energy faccilities can be built
Commissioner of Public Lands	Title 36	Protects and manages State lands	Responsible for administering, leasing, and managing State lands
Land Use Administration	Land Use Planning Act	Protects and manages State lands	Requires county land use plans, which could conflict with or require modification of some energy development proposals
State Engineer	Industrial Development Information and Siting Act	Administers and protects State waters	Any storage, impoundment, pipeline, diversion, or use of surface or groundwater for mining and coal processing requires a permit

SOURCE: U.S. Department of the Interior, Bureau of Land Management, *Federal Coal Management Program, Draft Environmental Impact Statement Supplement* (Washington, DC: U.S. Government Printing Office, 1985).

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Chapter 5

Baseline and Monitoring Data

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Chapter 5

Baseline and Monitoring Data

CHAPTER OVERVIEW

Overall, the quantity and quality of data collected for reclamation planning have improved dramatically since the passage of the Surface Mining Control and Reclamation Act of 1977 (SMCRA). However, data-related problems still place important limitations on both reclamation in the field and the advancement of reclamation science. First, data inadequacies still exist for some aspects of reclamation. These usually are the result of limitations in current state-of-the-art data collection methodologies, rather than operators' failure to carry out the necessary data collection.

In some cases, natural obstacles limit operators' ability to collect reliable data on some parameters. The mobility and adaptability of wildlife make it unlikely that highly reliable data suitable for quantitative species population analyses ever will be available. Similarly, infrequent and unpredictable flow events in ephemeral streams and extremely long spoil-aquifer recharge times will limit the availability of these hydrologic data in the West. **These obstacles are unlikely to be overcome soon and reclamation planning will have to continue to adjust its methods to the uncertainties in these areas.**

We can reasonably expect other data inadequacies to be overcome soon. The lack of techniques for generating chemical data about overburden is a serious limitation on the ability to delineate overburden materials that may be detrimental to revegetation or postmining water quality. Operators are developing new sampling, sample preparation, and laboratory techniques so that they can identify unsuitable materials and keep them out of reconstructed root zones and postmining water tables as much as possible.

Second, the lack of coordination in data collection is a serious obstacle to *regional* data compilation and analysis. This is particularly true in hydrology, for regional cumulative hydrologic impact assessments (CHIAs). The three CHIAs completed to date on Western mining areas uncovered serious, but not prohibitive, data inadequacies. To be valid in the quantitative models used for these mandatory assessments of regional impacts, hydrologic data must be collected at the same time and with the same methods. Initial steps are being made toward the necessary standardization, but coordination of data collection efforts remains the exception rather than the rule.

The lack of standardized methodologies for collection of some data seriously limits their usefulness. The lack of standardized surface water quality collection methods, especially for ephemeral streams, limits the usefulness of these data in determinations of the probable hydrologic consequences (PHC) of mining, as well as in CHIAs. As discussed in chapter 7, this data gap also makes it difficult to apply hydrologic performance standards.

Wildlife is another discipline for which standardized data-collection methodologies are lacking. Wildlife baseline studies now emphasize the description and delineation of habitats, rather than data collection about animal populations. But standard methodologies for the quantitative characterization of the various physical and floral features of wildlife habitat are not available. Development of such methodologies is necessary for assessing wildlife impacts and designing mitigation measures. Standardization is particularly important for wildlife data of regional concern—as large mammal, raptor, and bird data are—because such data have many potential users.

A third, and equally important, concern is that **the quantity of data being collected has created serious data management problems for both regulatory authorities and operators. Data collection often outpaces analysis** in the current reclamation permitting and monitoring process. It is not uncommon for regulatory authorities to require data to be collected and submitted, but to have insufficient time and other resources to analyze or review it. Also, **data frequently are presented in a format that contributes to data management problems.** Except for more recent permits in Wyoming and Colorado, there is no standard format for the applications. This makes it difficult for potential outside users to find information.

In part due to these data management problems, and in part due to limited regulatory authority resources, monitoring data are not used consistently or effectively. These data must be collected so that both operators and regulators will know how reclamation is progressing and what changes are needed in the mining and reclamation plan. In many areas, however, the collection of monitoring data has become perfunctory. Only in Wyoming has the regular review of monitoring data become part of the State's annual permit review process. Even there, personnel are not available to analyze all monitoring data the operators submit. In addition, monitoring data are rarely accessible by computer, or even indexed, and therefore are very difficult to review.

OTA was unable to determine whether all baseline and monitoring data collected are necessary, or whether all necessary data are being collected. We did find, however, that data collection requirements usually are not derived from any systematic examination of data uses in the reclamation planning and evaluation processes. Except for wildlife data, there is no "scoping" process (similar to the process used to support an environmental impact statement) to identify necessary data. Furthermore, in some disciplines or jurisdictions, these requirements have not been reviewed or updated since approval of the initial regulatory programs. Since that time, operators and regulators have learned a great deal about what data are actually needed and used to plan and evaluate reclamation—lessons that may not be reflected in data requirements.

OTA did not find redundancy in data collection to be a significant problem *within* the mine permitting process. Data needed for permit applications are site-specific. Thus, data collected for other mine sites rarely provide more than background information for permit applicants and regulatory authorities. **As mining in the West expands and the amount of permit data available grows, however, Federal agencies and research groups may find themselves repeating the data collection efforts of permit applicants if the data in permit applications are not made more accessible and useful.**

BASELINE AND MONITORING DATA: USES AND COLLECTION REQUIREMENTS

Data on surface and groundwater hydrology, geology, soils, overburden, vegetation, wildlife, and other mine-site features and resources form the foundation of all reclamation planning and evaluation. These data may be divided into two broad categories. Operators collect **baseline data** before mining to aid in the formulation of the mining and reclamation plan that is submitted as part of the permit application package. Baseline data enable the operator to predict the impacts of mining and to define the postmining land use.[1] Operators collect **monitoring data** during and after mining and reclamation to track the impacts of mining and judge the success of reclamation, and to refine the mining and reclamation plan if necessary. Without enough valid baseline data, the techniques used to analyze the data will produce unreliable and misleading results. Without sufficient valid monitoring data, the success of reclamation cannot be evaluated.

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[1] If mining began before implementation of the Federal and State regulatory programs under SMCRA, mines had to be repermitted under those programs, and operators usually undertook baseline studies soon after SMCRA was approved to support repermitting. Many of the case studies presented in vol. 2 describe older mines where baseline studies postdate the beginning of mining. See, for example wildlife case studies D and H, soils case D. But also note hydrology cases 3.7 and 3.18, where monitoring began before SMCRA.

This chapter surveys data collected for or used in reclamation planning and evaluation, with emphasis on data management, and data gaps or the collection of unnecessary data. The chapter reviews and compares regulatory requirements for data collection, both at the Federal level and within the five States in the study area. It identifies methods used to collect the required data and discusses the relative merits of and limitations of the various methods. Special attention is paid to disciplines in which good data are not being collected, either because current collection methods are inadequate or are not standardized, or because there are natural obstacles to the development of collection methods. Because this study was prompted in part by a criticism that much of the data collected at great expense are not used, or are not used optimally, special attention is also given to more efficient use and better accessibility of data.

Data collection methods and data-related problems are radically different in each of the reclamation disciplines. Hydrology is a highly quantitative discipline in which vast amounts of numerical data are collected and managed. Large quantities of numerical overburden data also are collected, but their analysis is a very young science and not all of the necessary techniques have been fully developed. Wildlife biology is a less quantitative discipline in which the mobility and natural variability of wildlife populations limits the ability to collect valid numerical data. Therefore, relatively few quantitative wildlife data are collected and their meaning is subject to varying professional interpretations. Vegetation science and data collection techniques are, by contrast, well established. Operators (and others) use so many different techniques for collecting each type of vegetation data, however, that aggregation of data for regional analyses is almost impossible.

Data collection requirements for each discipline are almost entirely State requirements, based on the general guidelines established in SMCRA and the Federal regulations (see ch. 4). Thus, baseline and monitoring data requirements vary with the different environments, prevalent postmining land uses, and other concerns peculiar to each State. Some State requirements for some disciplines have changed since the Federal permanent regulatory program was first promulgated in 1979, and they are still changing. At the time of this writing, Montana and Colorado are revising their regulations and guidelines (7). The Montana and Colorado requirements discussed here are those in force as of April 1985. It should also be noted that a number of these regulations, including requirements for the scope of hydrologic data for PHC determinations and CHIAs, were challenged successfully in Federal court and must be rewritten by the Office of Surface Mining (OSM) and the States (see ch. 4, box 4-C).

SOURCES OF DATA

The surface mining and reclamation permitting and evaluation processes outlined in chapters 4 and 7 are very data intensive, and permit applicants and regulatory authorities turn to a wide range of data sources to meet SMCRA's data collection requirements. As companies first begin to prepare a mining and reclamation plan, they compile data available in the published literature or in the files of various Federal and State agencies. These data are then supplemented with site-specific field data collected to support the permit application package. Data collected by the operators during mining and reclamation monitor the progress of reclamation and serve as the basis for evaluating reclamation success.

Data Collected Outside of the Permitting Process

In fulfilling data requirements for surface mining permits, operators naturally turn first to existing sources of data. The U.S. Geological Survey (USGS), the Bureau of Land Management (BLM),[2] the U.S. Fish and Wildlife Service (FWS), the Soil Conservation Service (SCS), State fish and game and other agencies, university researchers, and many other groups collect data on the soils, geology, hydrology, vegetation, wildlife, and other resources of the Western coal regions for their own purposes. These data may also be useful in planning surface mine reclamation. In addition, the data in the permit application for one surface mine may be helpful in permitting at nearby mine sites. Making maximum use of such sources of data is in everyone's interest. It saves time and money for operators and contributes to the efficiency of the permitting process.

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[2] BLM's Energy Mineral Rehabilitation Inventory and Analysis (EMRIA) reports may be particularly helpful as general compendia of data on all resources on a particular lease tract; see ch. 9.

However, data collected outside the permitting process will not meet all of the requirements for the permit application package, and their usefulness to applicants varies. Sometimes data may be directly useful and operators may even include them in permit applications. These include USGS geologic and hydrologic data and SCS soils data, although even these usually must be augmented to meet State requirements for site-specific data. Other data, such as most of the available vegetation and wildlife data, are helpful only as the most general background information, but may provide a starting point and guide for an operator's own data collection efforts.

There are several reasons that data collected for other purposes are of limited usefulness to permit applicants. First, **the intensity and areal extent of the data rarely are compatible with permit requirements.** Most regional data are too few over too large an area to fulfill permitting requirements. They can, however, give a preliminary profile of the mine site and surrounding area, and thus may highlight potential reclamation problems or other factors that need special attention in site-specific data collection and analysis. Conversely, data from academic or independent research projects are often too intense over too small an area to be directly useful as permitting data.

Second, **quality control problems exist with many of these data**. They may have been collected improperly or with techniques not approved by the regulatory authority. Third, **the data may be inaccessible.** Some data are proprietary (e.g., exploration data on coal resources submitted to BLM and OSM). Other data are simply in unmanageable formats. Accessibility limits the usefulness of most available data to at least some degree. Few of the existing data related to surface mining are accessible by computer; most have not been published. Perhaps the best example of valuable but relatively inaccessible data are the permit applications, themselves (see box 5-A).

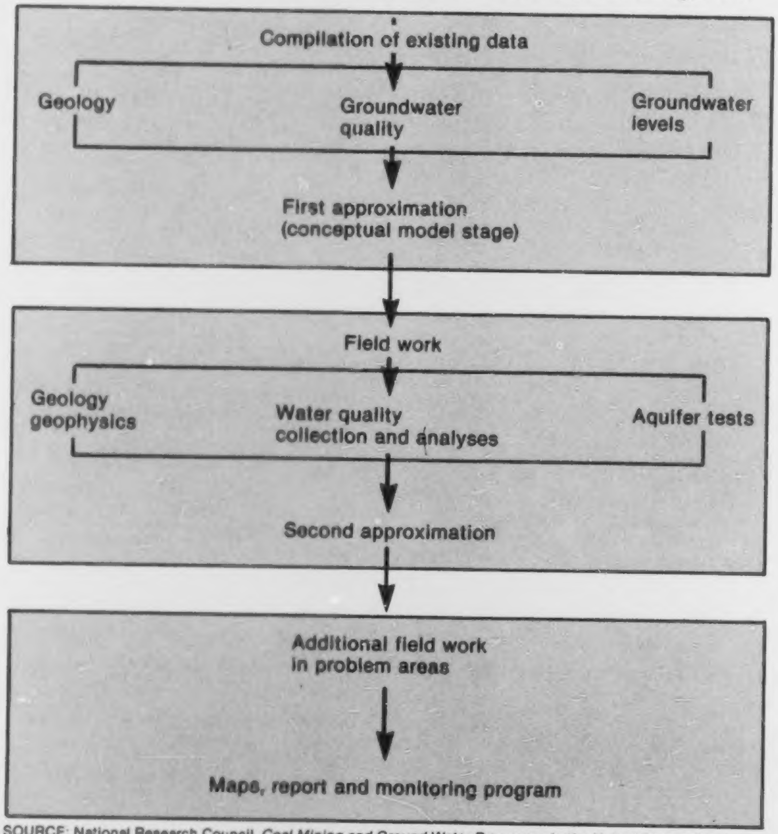
Collection of Site-Specific Data by Operators

Despite their limitations, data collected outside the permitting process often allow permit applicants to make a preliminary outline of a mining and reclamation plan. Using this first, very rough plan, an applicant can identify data needs for permitting and reclamation planning more precisely, and thus can design more intensive, site-specific,

Box 5-A.—Use of Data in Permit Application Packages

Permit application packages for other surface mines in an area have the potential to be one of the most useful sources of preexisting data for permit applicants. While data from one mine's permit cannot be substituted for the site-specific data necessary for permitting a new mine, they can be invaluable inputs into the analyses required in permit applications; for example, correlations of toxic strata in overburden, groundwater quality and quantity calculations, analyses of wildlife impacts. However, permit applicants rarely use these applications, primarily because the format of the data and of the applications themselves poses a formidable obstacle to efficient utilization. Permit applications have grown in size over the past several years so that, on average, they consist of 25 to 30 three-inch thick three-ring binders lined up on shelves in OSM and State regulatory authority offices. The data in the applications are not accessible by computer, or reduced in any way. With the exception of more recent applications from Wyoming and Colorado, there is no standard format for organization of the permit application packages or for presentation of data and analyses. The lack of specified formats is compounded by the absence of any sort of "scoping" process for data collection, which frequently leads to permit applicants' collecting more data than actually are needed to support the demonstrations required in SMCRA.

Figure 5-1.—A Conceptual Approach to Hydrogeologic Investigations


Compilation of existing data
Geology
Groundwater quality
Groundwater levels
First approximation (conceptual model stage)
Field work
Geology geophysics
Water quality collection and analyses
Aquifer tests
Second approximation
Additional field work in problem areas
Maps, report and monitoring program

SOURCE: National Research Council, *Coal Mining and Ground-Water Resources in the United States* (Washington, DC: National Academy Press, 1981) p. 153.

data collection programs. As these site-specific data are collected for permitting, the mining and reclamation plan is continually refined. This refinement continues after the onset of mining, as monitoring data yield additional information that is incorporated into the plan. Figure 5-1 illustrates this refinement process for hydrogeology; the process in other disciplines is similar.

A common, and sometimes unavoidable, shortcoming of baseline studies is that they provide only a snapshot of premining conditions over a narrow period of time. The narrow temporal focus of baseline data can be particularly problematic in assessing hydrology, vegetation, and wildlife, which may vary greatly over time with climatic and other conditions or natural succession processes. Mining impacts and reclamation success can only be evaluated if some idea of the range of natural variation in these disciplines has been established in the baseline surveys.

In some instances, data collection over the time required to document the full range of this natural variation is impractical. For example, for obvious statistical reasons, baseline studies are unlikely to document a 25-year, 24-hour flow event in an ephemeral stream. Similarly, baseline studies are unlikely to document either the natural vegetative succession on the site or the effects of long-term climatic cycles. Other significant variations over shorter periods of time, particularly seasonal variations, can and should be documented with baseline data, however. Ways of compensating for lack of actual data on long-term variations are discussed in chapter 6.

As with baseline data, monitoring data must be collected over sufficient periods of time to account for the range of natural and seasonal variations. Some amount of monitoring is mandated under the regulatory programs and/or stipulated by regulatory authorities in permit approvals. Also, operators often undertake monitoring programs on their own initiative to help them plan their operations and identify any reclamation problems early, when correction of those problems may still be relatively simple and inexpensive.

SOILS AND OVERBURDEN[3]

Data Requirements

State and Federal data collection requirements for soils and overburden are summarized in table 5-1. All five States require a soil map at about the same scale, and Montana, New Mexico, and Wyoming describe the level of detail of required mapping in their guidelines. The minimum size of soil units that must be mapped varies from 0.5 to 2 acres. Soil sampling, which is important in the characterization of soil chemistry, varies from one to six profiles required per mapped unit. Requirements for chemical and other analyses of samples differ somewhat, but all States require analyses for pH, electrical conductivity (EC), moisture content saturation (Sat percent), sodium adsorption ratio (SAR), and texture.

Four of the five States require geologic maps showing both coal croplines and dip. All five require cross-sections showing the seam(s) to be mined, any thin seams above or below the coal to be mined (''rider'' seams), and the underburden (see fig. 5-7, below). All five States also require lithologic logs of overburden drilling, but only North Dakota requires geophysical logs.

All of the States studied except North Dakota have guideline suggestions for chemical analyses of selenium, boron, and acid-base potential.[4] Each of these four States also defines, in rules or guidelines, required trace element tests. Wyoming did require quality assurance samples for overburden analytical work so that analyses could be spot-checked and verified by another lab, but recently rescinded this requirement.

All five States require the identification of potentially acid-, alkaline-, and toxic-forming zones of overburden that may adversely affect revegetation or postmining water quality, but only in Wyoming do the cross-sections have to show these zones. These cross-sections can be difficult to prepare because the zones may not occur in predictable, mappable units. Also, the scale of cross-sections is so large relative to the scope of potentially deleterious zones that the zones do not appear (see ch. 6).

Overburden drilling is the method used to characterize overburden and to determine the location and extent of deleterious strata. Required intensity for overburden drill holes ranges from one hole per 40 acres in Montana, North Dakota, and Wyoming, to one hole per 640 acres in Colorado. **The changes in lithology and geochemistry over short distances in many of the Western coal regions, particularly the Powder River basin, have spurred considerable debate about whether higher intensity drilling results in more accurate overburden characterization. Available data suggest that the accuracy of unsuitability characterization is not much better at one hole per 40 acres than at one hole per 640 acres.** One study found that an extremely high (and very expensive) intensity of 195-foot spacing between drill holes (or slightly over one hole per acre) would be required to predict the occurrence of deleterious strata in overburden with 80 to 90 percent accuracy (4). Not all mine sites are so geologically variable, however, and, at those that are,

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[3] Unless otherwise indicated, the material in this section is adapted from reference 13.

[4] Mines in the Fort Union region of North Dakota may have highly sodic clays in the overburden, but the requirement for 4 feet of suitable cover over all spoils in that State is considered sufficient to protect the root zone.

Table 5-1.—Selected Requirements for Baseline Studies From Regulations and Guidelines

Item	*Federal* (30 CFR 700.1 1984)	*Colorado* (MLRD 1981 and MLRD 1983)	*Montana* (DSL 1980 and DSL 1983)	*New Mexico* (MMD 1980 and MMD 1984)	*North Dakota* (NDPSC 1983 and NDPSC 1984)	*Wyoming* (WDEQ 1980 and WDEQ 1984)
Soils:						
Map, base map requirements	yes (R-770.21)[a]	yes (R-2.04.9)	yes; 1″=400′ (G-I,B.2)[b]	1″=500′ min.(G)	yes; 1″=400′ (R-69-05.2-08-10)	yes; 1″=400′-700′ (G-I,B)
Minimum size map unit delineation	not addressed	not addressed	1 acre minimum (G-I,B.1)	½ acre minimum (G)	not addressed	2 acre minimum (G-I,B)
Sampling intensity	not addressed	based on complexity (R-2.04.9)	3 representative locations (G-I,D.2)	up to 6 profiles (G)	not addressed	up to 3 profiles (G-I,B)
Depth of sampling	not addressed	not addressed	7 ft (G-I,D.1)	6 ft (G)	up to 5 ft	5 ft (G-I,B)
pH, EC, Sat%, texture	not addressed	yes [R-(1)(b)]	yes (R-26.4.304)	yes (G)	yes (R-69-05.2-08-103)	yes (G-appendix 1)
SAR, ESP	not addressed	SAR (R-2.04.9)	SAR, ESP (G-I,E)	SAR (G)	SAR, ESP (R-60.05.2-08-103)	SAR (G-appendix 1)
Se, B	not addressed	not addressed	Se, B (G-I,E)	Se, B (G)	not addressed	Se, B (G-appendix 1)
Trace metals	not addressed	not addressed	not addressed	Mo, Cu (G)	not addressed	not addressed
Other	not addressed	other chemical analysis as required (R-2.04.9)	% OM (G-I,E)	$CaCo_3$ (G)	free lime %, %OM (R-69-05.2-08-10)	$CaCo_3$, coarse fragments dry and moist consistency No_3-N, P, %OM, K, particle (G-appendix 1)
Overburden:						
Geologic map coal crop lines, strike-dip	yes (R-779.25)	yes (R-2.04.6)	not specified	yes (R-8-25)	yes (R-69-05.2-08-05)	yes (R-ch. II, sec. 3)
Overburden isopach map	not specified	not specified	not specified	not specified	yes (R-69-05.2-08-05)	yes (G-II, B)
Cross-sections; mined seams, rider seams, underburden	yes (R-779.25)	yes (R-2.04.6)	not specified	yes (R-8-25)	yes (R-69-05.2-08)	yes (R-ch. II sec. 3) delineate potential toxic zones (G-II, B)
Drill hole intensity	not specified	1 hole/640 acres, 3 holes minimum (G-table 3. B.1.)	1 hole/40 acres, more for suspect areas (G-III, D.2)	1 hole/150 acres, minimum of 3 holes; (G)	1 hole/40 acres (R-69-05.2-08-05)	up to 1 hole/80 acres; up to 1 hold/40 acres for special handling (at least two cores per section) (G-II,B)
Sample interval	not specified	4 to 10 ft (G-table 3.B)	not specified	2-10 ft (G)	5 ft (R-69.05.2-08-05)	5 to 10 ft (G-2,B)
Quality assurance split sampling	not addressed	not addressed	not addressed	not addressed	not addressed	ea. 10th in triplicate, ea. 20th by 2 other labs (G-II,B) (recently omitted)

Table 5-1.—Selected Requirements for Baseline Studies From Regulations and Guidelines—Continued

Item	*Federal* (30 CFR 700.1 1984)	*Colorado* (MLRD 1981 and MLRD 1983)	*Montana* (DSL 1980 and DSL 1983)	*New Mexico* (MMD 1980 and MMD 1984)	*North Dakota* (NDPSC 1983 and NDPSC 1984)	*Wyoming* (WDEQ 1980 and WDEQ 1984)
Lithologic logs	yes (R-780.22)	yes (R-2.04.6)	yes (G-III,C.31)	yes (R-8-14)	yes (R-69-05.2-08-05)	yes (G-II)
Geophysical logs	not specified	not specified	not specified	not specified	yes (R-69-05.2-08-05)	1 geophysical log/1,000 ft (G-II,B)
Identify acid and toxic forming strata	yes (R-780.22)	yes (R-2.04.6)	yes (R-26.4.304)	yes (R-8-14)	yes (R-69-05.2-08-05)	yes (R-ch. II, sec. 2)
ESP, SAR	not addressed	SAR (G-table 3.A)	ESP, SAR	SAR (G)	SAR (R-69-05.2-08-05)	SAR (G-appendix 1)
Se, B	not addressed	Se, B (G-table 3.A)	Se, B (G-III D.5)	Se, B (G)	not addressed	Se, B (G-appendix 1)
ABP, sulfur forms	not addressed	pyritic, sulfate, organic, total (G-table 3.A.)	ABP may be requested (G-III, D.5)	ABP (for some samples) G SO_4 (R-8-14)	not addressed	ABP (G-appendix 1) organic carbon
Trace elements	not addressed	Mo, Pb, As, Cd, Fe, Mn, Cu, Hg, Zn (G-table 3.A.)	Mo (G-III, D.5)	Al, As, Ba, Cd, Cr, Co, Cu, Cn, Fe, Pb, Hg, No, Ni, Ag, So-4, U, V, Zn, Ra-226, Ra-228 (R-8-14) Mo, Cu, (G)	not addressed	As, Mo (G-appendix 1)

[a] R—denotes topic addressed in regulations and the numbers following designate where it is discussed.

[b] G—denotes topic addressed in guidelines and the numbers following designate where it is discussed. The Montana Guideline has recently been rescinded.

SOURCE: James P. Walsh & Associates, "Soil and Overburden Management in Western Surface Coal Mine Reclamation," contractor report to OTA, August 1985.

economically realistic drilling intensities can at least identify parameters of concern and indicate areas where more intensive drilling might be appropriate.

The sampling densities needed for adequate postmining spoils monitoring also are in dispute. The Wyoming Department of Environmental Quality has recently begun to investigate the statistical basis for required sampling densities (both vertical and horizontal) on regraded spoils to ensure the adequate delineation of unsuitable material (18). An analysis of regraded spoil data from one mine concluded that, to distinguish adequately between 6-acre parcels with 95 percent confidence, approximately three to five samples were needed for an adequate description of their differences in pH, salinity, and Sat percent (two samples at 80 percent confidence). Six-acre parcels could not be distinguished from one another when analyzing for acid-base potential. Similar analyses may be required for the parameters of concern at every mine to determine adequate sample densities for regraded spoils.

Sources of Previously Collected Data

Soil Conservation Service Soil Survey Reports are available for most of the coal fields and are used almost universally as the starting point for more intensive soil inventories on the mine site. The SCS data are collected according to a uniform National Cooperative Soil Surveys methodology. The reports include soil maps, descriptions of map units, soil series descriptions, typical pedon descriptions,[5] soil classifications, and limited chemical and physical data and interpretations. SCS soil surveys can be of five different orders, with first order surveys being the most detailed. Table 5-2 shows the criteria used for the different orders of surveys. Surveys available for potential mining sites are usually order two for cropland and order three for rangeland.

The U.S. Geological Survey is probably the most common source of background geologic data on regional geology, stratigraphy, and lithology. Data are readily available for virtually all coal regions. The quality of the published information is very high but the compilation and publication process is extremely slow. Open-file reports are available for projects in progress.

Data Collection by Operators

Because soils and overburden do not vary with seasonal and climatic changes, the data are not time-dependent and could be collected all at once. As a practical matter, however, both sets of data are collected in stages to optimize information gathering at reasonable cost. After examining the available SCS and USGS data, operators formulate a baseline data-collection program in consultation with the regulatory authority, and then collect the data according to methods described below. Using the baseline data, operators identify potentially unsuitable areas on their site. These areas receive special attention in subsequent sampling and sample analysis.

Unsuitability is more of a concern with overburden than with soil because the disturbance and consequent exposure of overburden to the surface environment causes physical changes as well as chemical reactions from oxidation and leaching. Yet data on the potential for such reactions are difficult to collect because the overburden is buried and because unsuitable materials may only occur in very isolated pockets. Soils, on the other hand, usually are more nearly in chemical equilibrium with the surface environment. While disturbance of soils prompts new chemical reactions, soil material has already been oxidized and leached. Therefore, such reactions in soils are unlikely to pose as much of a potential threat to the success of reclamation as, for example, oxidation of pyrites in overburden. Moreover, soils are easily observable and accessible, so unsuitable materials are relatively easy to delineate.

Soil baseline studies begin with a site-specific soil inventory, usually more detailed than the available SCS soil surveys. The intensity of inventories varies among States and mines, but most are detailed order two or general order one (see table 5-2). Scales for soil maps range from 1 inch equals 400 feet (1:4800) to 1 inch equals 800 feet (1:9600), as per State guidelines. The inventories typically include soil maps (fig. 5-2), map unit

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[5] A pedon is a three-dimensional body of soil with lateral dimensions large enough to permit the study of soil horizon shapes and relations; its area ranges from 1 to 10 square meters.

Table 5-2.—Key for Identifying Kinds of Soil Surveys

Level of data needed	Field procedures	Minimum size delineation hectares[a]	Typical components of map units	Kinds of map units[b]	Appropriate scales for field mapping and publication	Kind of soil survey
Very intensive (i.e., experimental plots, individual building sites)	The soils in each delineation are identified by transecting or traversing. Soil boundaries are observed throughout their length. Remotely sensed data is used as an aid in boundary delineation.	1 or less	Phases of soil series, miscellaneous areas	Mostly consociations, some complexes	1:15,840 or larger	1st order
Intensive (i.e., general agriculture, urban planning)	The soils in each delineation are identified by transecting or traversing. Soil boundaries are plotted by observation and interpretation of remotely sensed data. Boundaries are verified at closely spaced intervals.	0.6 to 4	Phases of soil series; miscellaneous areas; few named at a level above the series	Consociations and complexes; some undifferentiated and associated	1:12,000 to 1:31,680	2nd order
Extensive (i.e., rangeland, forestland, community planning)	The soils are identified by transecting representative areas with some additional observations. Boundaries are plotted mostly by interpretation of remotely sensed data and verified with some observations.	1.6 to 256	Phases of soil series and levels above the series; miscellaneous areas	Mostly associations or complexes; some consociations and undifferentiated groups	1:20,000 to 1:250,000	3rd order
Extensive (i.e., regional planning)	The soils are identified by transecting representative areas to determine soil patterns and composition of map units. Boundaries are plotted by interpretation of remotely sensed data.	40 to 4,000	Phases of levels above the series; miscellaneous areas; phases	Mostly associations; some consociations, complexes, and undifferentiated groups	1:100,000 to 1:1,000,000	4th order
Very extensive (i.e., selections of areas for more intensive study)	The soil patterns and composition of map units are determined by mapping representative areas and applying the information to like areas by interpretation of remotely sensed data. Soils are verified by occasional onsite investigation or by traversing.	1,000 to 4,000	Phases of levels above the series; miscellaneous areas	Associations; some consociations and undifferentiated groups	1:500,000 to 1:1,000,000 or smaller	5th order

[a] This is about the smallest delineation allowable for readable soil maps. In practice, the minimum size delineations are generally larger than the minimum size shown.

[b] Where applicable, all kinds of map units (consociations, complex, association, undifferentiated) can be used in any order of soil survey, and they are not identified as a particular order of map unit.

SOURCE: Soil Conservation Service.

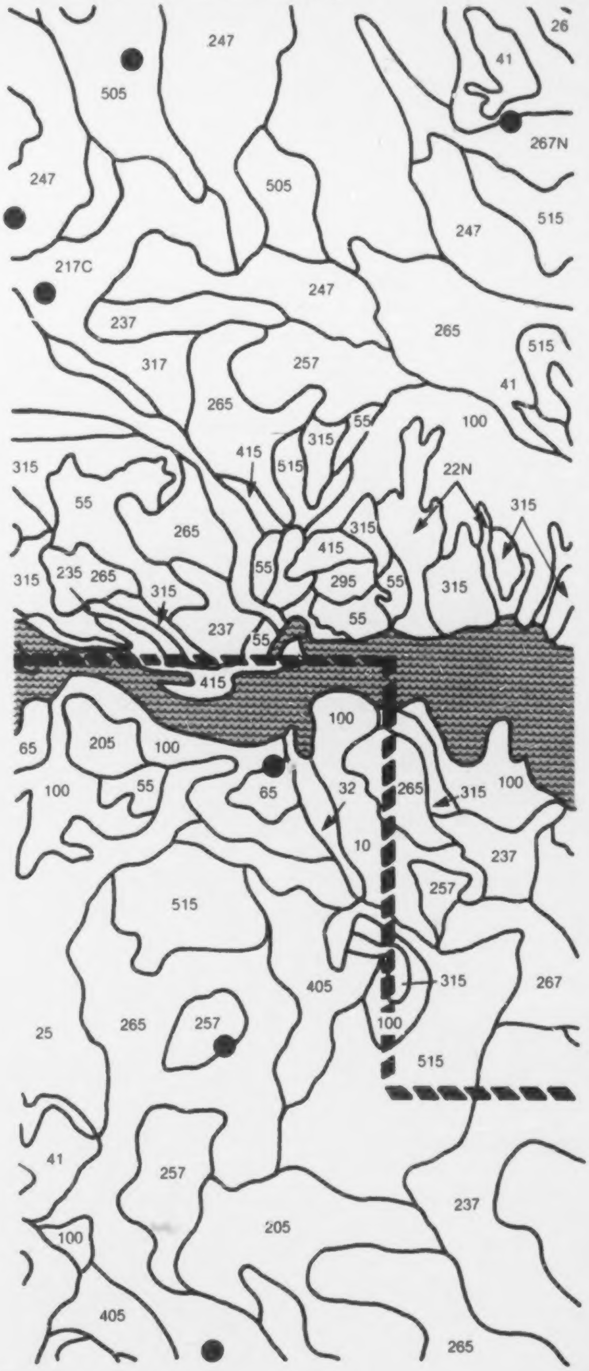
Figure 5-2.—Soil Map Legend and Portion of Soil Map

Soil classification legend

22	Kim clay loam
22S	Kimsal clay loam
22N	Nonkim clay loam
32	Limon clay loam
41	Samsil-Louviers complex
55	Single-shake complex
65	Thedalund loam
75	Wibaux channery loam
82	Reno clay loam
107	Tassle fine sandy loam
107N	Lessat fine sandy loam
117N	Embry fine sandy loam
121	Nomil clay
146	Dillingson very fine sandy loam
205	Cushman loam
217	Donkey fine sandy loam
217C	Donkman fine sandy loam
225	Fort Collins loam
237	Maysdorf fine sandy loam
247	Olney fine sandy loam
247N	Yenlo fine sandy loam
257	Pugsley fine sandy loam
257C	Pugman fine sandy loam
265	Renohill loam
267	Renohill fine sandy loam
267N	Rencalson fine sandy loam
295	Ulm loam
297	Ulm fine sandy loam
307N	Vonson fine sandy loam
315	Thunder loam
315C	Worfka loam
317	Thunder fine sandy loam
325	Worf loam
405	Abstinate loam
405P	Abstinate loam, ponded phase
407	Abstinate fine sandy loam
415	Absted loam
415N	Abman loam
417	Absted fine sandy loam
505	Bidman loam
505P	Bidman loam, ponded phase
515	Briggsdale loam
100	Shallow entisols
200	Porcelinite outcrops and very shallow soils
SL	Rockland, sedimentary rock
CUT	Structural cuts and fills

●	Sampling locations soil profile description locations
▨	Reservoir

Scale 1" = 1000'


247
26
505
41
267N
247
505
515
247
217C
247
237
265
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317
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41
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100
415
315
315
515
22N
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235
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415
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32
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55
10
237
515
257
405
315
267
25
265
257
100
515
41
257
237
205
100
405
265

SOURCE: BLM District Office, Casper, WY, personal communication.

descriptions (fig. 5-3), series descriptions, pedon descriptions (fig. 5-4), and a map legend.

One minor shortcoming was common in the soil surveys included in the permit applications OTA reviewed. Typically up to three soil phases made up most of each map unit with one or two other phases being minor inclusions. However, rarely did the application include an estimate of the percentage of the unit constituted by each major component and each inclusion. This omission would affect the accuracy of any volume calculation made from the soil survey because the various inclusions have different stripping depths.

Following the survey, soils are sampled for laboratory analysis of their chemical composition. Sampling intensity varies and in several States is specified by guidelines or regulations. Most often between one and three vertical profiles of the soil are taken in each type of mapped unit. The profiles are then sampled by horizon, usually with more detailed sampling in the upper horizons. Samples are tested for a fairly standard set of agronomic properties that typically includes pH; EC; SAR; Sat percent; percent organic matter (OM); and percent sand, silt, and clay. Tests for trace elements, boron (B) and selenium (Se), are often run on salty soils. Tests for nutrient elements such as nitrogen, phosphorus, and potassium (N, P, and K) also may be run during baseline studies, although they are more useful if run prior to reseeding. Standard procedures for all of these tests have been published by the U.S. Department of Agriculture (USDA) (11). Even using standard techniques, however, variations in the results of the same test on the same sample run by different labs can be significant for some chemical parameters.[6]

Figure 5-3.—Example of a Soil Map Unit Description

125—Armolls channery sandy loam, 20 to 35 percent slopes

These are deep, well-drained soils on ridges and sideslopes throughout the permit area at elevations of 3,200 to 3,450 feet. They developed in residuum weathered from fractured Fort Union sandstone. Average annual precipitation ranges from 13 to 19 inches, and the frost-free season is typically 110 to 125 days. Mean annual soil temperature ranges from 42 to 46° F. Slopes are moderately steep to steep.

Typically the surface layer is brown or reddish brown calcareous channery sandy loam about 4 inches thick. The upper part of the substratum is brown or reddish brown calcareous very channery sandy loam about 8 inches thick. The lower part of the substratum is reddish yellow calcareous very channery sandy loam to depths of 60 inches or more. In some profiles the surface layer is leached of calcium carbonates. Coarse fragments comprise 35 to 75 percent of the soil, by volume. The unit is typical of the series.

Permeability is moderately rapid. The available water holding capacity is low. Effective rooting depth is 60 inches or more. Surface runoff is medium and the erosion hazard is slight from wind and water. The unit is in pine woodland with an understory of native range.

Land Capability Classification: VIIs

Topsoil Suitability

This unit is unsuited to use as a source of topsoil because of its high content of coarse fragments.

Prime Farmland Considerations

The Armolls soil falls outside the scope of prime farmland criteria on the basis of its steep slopes, arid moisture regime, and stoniness.

Post-Mining Erosion Hazards

Depending on the size and amount of coarse fragments, this soil may be spread over a wide area, which would essentially eliminate the hazard of erosion from this material. More probably, the material should be buried during grading.

SOURCE: James P. Walsh & Associates, "Soil and Overburden Management in Western Surface Coal Mine Reclamation," contractor report to OTA, August 1985.

Figure 5-4.—Example of a Soil Pedon Description

NELAR SERIES

Classification: Entic Haplustoll-coarse-loamy, mixed, mesic family.

Location: Sec. 11 T9S R40E 400 feet north and 150 feet east of W1/4 corner in road cut.

Profile Description: Nelar loam.

A_1 Reddish brown (5yr4/4 when dry) light loam; dark reddish brown (5yr3/4 when moist); moderate fine and very fine granular structure; soft when dry; very friable when moist; nonsticky and nonplastic when wet; few flat fragments.

C_1 ca 8-36" Light reddish brown (5yr6/3 when dry) light loam; reddish brown (5yr4/3 when moist); weak coarse prismatic structure; slightly hard when dry; very friable when moist; nonsticky and nonplastic when wet; very strong effervescence with a few threads of lime; few lime coated angular fragments.

C_2 36-80" Reddish brown (5yr5/4 when dry) light loam and fine sandy loam; reddish brown (5yr4/4 when moist); massive; soft when dry; very friable when moist; nonsticky and nonplastic when wet; strong effervescence; few lime coated angular fragments.

Range in Characteristics: The texture of control section is loam or sandy loam with less than 12 percent clay and less than 15 percent by volume of angular fragments. Bedrock is typically deeper than 5 feet but can occur above this depth in some profiles. The sandy loam substratum can occur at any depth below 30 inches. In places a very weakly expressed B_2 horizon is present.

Colors are in hues redder than 7.5yr.

SOURCE: James P. Walsh & Associates, "Soil and Overburden Management in Western Surface Coal Mine Reclamation," contractor report to OTA, August 1985.

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[6] See reference 13, table 4.2-1 which summarizes some results of round-robin soils tests conducted by the Montana DSL; see also reference 2. The USGS has conducted similar tests recently with similar results (10).

Additional soils data are collected to plan soil handling in order to optimize stripping depths and maximize soil recovery. In rare instances, such additional data are superfluous (e.g., in parts of New Mexico there is no suitable topsoil). However, in much of the West, 100 percent topsoil recovery is a major concern. In these areas, following baseline studies but before the onset of mining, transects (narrow belts) are used to refine soil classifications and stripping depths. The soil is then staked at close spacings (every 200 feet is common) with markings on each stake indicating the stripping depth at that particular spot. At larger operations, a soil scientist may assist the scraper operator to ensure maximum topsoil recovery. Many mines (particularly in Wyoming) are required to maintain "budgets" of their total soil volume. In Wyoming and North Dakota, operators commonly demonstrate full topsoil recovery to the regulatory authority by leaving pillars of topsoil at specified intervals.

Overburden baseline studies center around the overburden drilling and sampling requirements in the five States. Required spacing of drillholes ranges from one hole per 40 acres to one hole per 640 acres. Holes generally must be sampled at 5- to 10-foot intervals through the overburden. Samples may be collected either from the cuttings from rotary drill holes or from continuous core samples. Rotary drilling is a somewhat crude method of collecting samples as there is some mixing of cuttings as they rise in the hole. The alternative, coring, is much more expensive. Therefore, it is rarely used for overburden characterization beyond the initial baseline study, for which some core samples may be required (e.g., in Wyoming). Overburden samples collected at later stages, during developmental and blasthole drilling, are all from rotary drill holes.

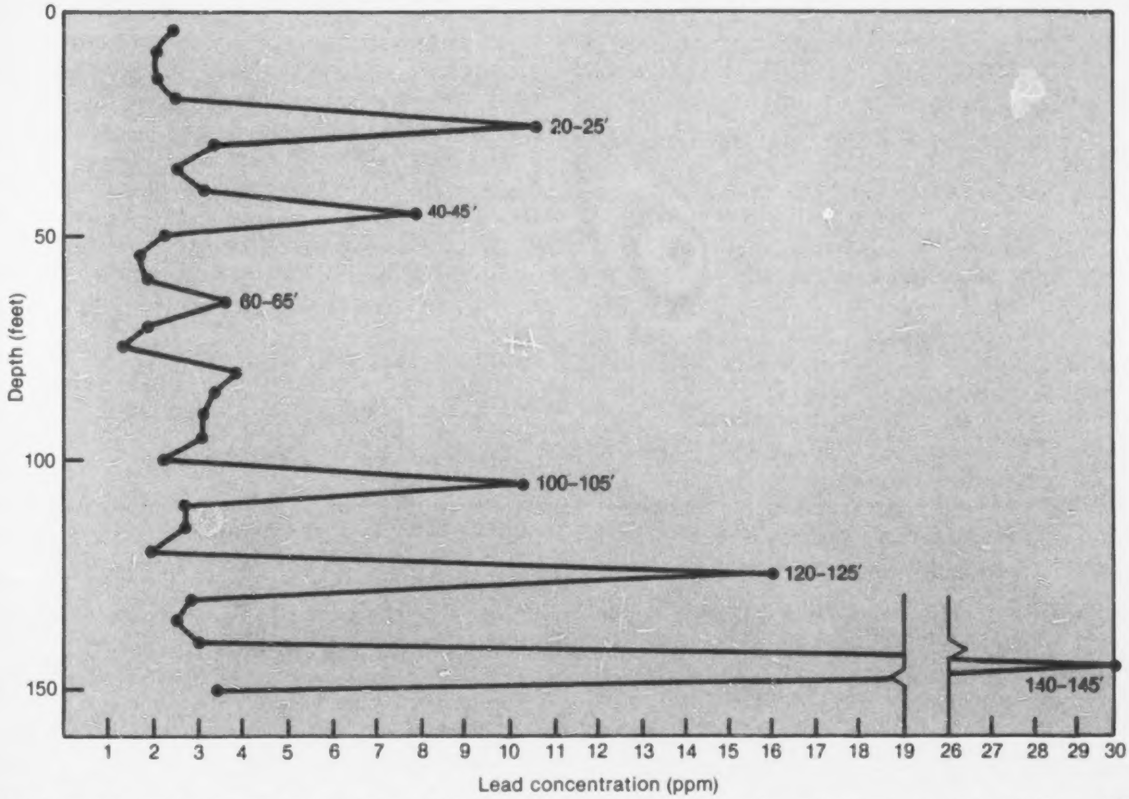
For overburden, these additional samples are first collected during developmental drilling, which usually precedes the path of mining by about 5 years. Developmental drillholes are more closely spaced than baseline holes; operators use them to refine coal seam maps. If an initial baseline drillhole indicates the potential for unsuitable material, developmental drillholes may be sampled around the baseline hole. If the extent of the material is still not clear or if further information is needed, additional overburden samples may be taken during the drilling of closely spaced blastholes (used to loosen the overburden immediately before mining). Even this progressively more intensive data collection may only satisfactorily delineate deleterious material that occurs in contiguous, mappable strata usually of carbonaceous shales or pyritic sandstones. The occurrence of isolated pods of undesirable material, usually containing high levels of trace metals such as arsenic or boron, cannot be mapped with any economically reasonable density of drillholes (see ch. 6).

Sample contamination from pipe grease and drilling fluids has been a problem in both coring and rotary drilling. Depending on the nature of the contamination, it may be easy to spot (as in fig. 5-5, where high lead concentrations were reported at regular 20-foot intervals over the length of the drill stem). In other cases, contamination is more difficult to detect (see box 5-B). Oxidation of overburden samples also can affect the lab test results, but is usually only a problem when samples have been stored for long periods, for example when samples taken before 1977 are tested for the parameters now required under SMCRA regulations.

A geologist compiles a *lithologic log* for each drillhole either from the core, from cuttings collected onsite, or from the driller's logs. Figure 5-6 is an example of a page from a typical lithologic log. Western lithologic descriptions are not standardized, and in some of the permit applications reviewed by OTA, lithologic descriptions were sketchy, with one word descriptions of rock types such as "shale" or "sandstone." The developers of a standardized rocktype key for the Eastern United States (6) recently published a similar lithologic key for Western coal overburden (5). This key standardizes lithologic descriptions and reduces each standard type to a numerical code. This facilitates compilation of overburden databases and use of the growing variety of overburden software programs.

After a hole has been drilled, a variety of probes are lowered down into it to develop a *geophysical log*. These probes measure parameters such as electrical conductivity and resistivity, natural

Figure 5-5.—Plot of Lead Concentration Versus Depth



SOURCE: James P. Walsh & Associates, "Soil and Overburden Management in Western Surface Coal Mine Reclamation," contractor report to OTA, August 1985.

Box 5-B.—Contamination of Overburden Samples[1]

During review of one permit application in 1978 to 1979, the Montana regulatory authority expressed concern about high levels of molybdenum (179 ppm) in spoil analysis data from a clayey interburden. Molybdenum can be taken up into vegetation and, at elevated levels, can cause molybdenosis in grazing cattle. DSL granted the permit, but with the stipulation that a study of potential molybdenum problems at the site be conducted. The study revealed that the original spoil samples were collected using a pipe grease containing 10 percent molybdenum. Therefore, the high values could have been the result of sample contamination. The study also found that the molybdenum content of vegetation growing on spoils mixed with the interburden was not significantly different from that of vegetation grown on spoils from which the interburden had been removed. More samples were collected, avoiding contamination. These values were much lower, but still above the State's suspect level. However, because the mix of interburden into the spoil had been shown to produce acceptable vegetation and because of other constraints on the operator, DSL agreed to allow the operator to mix the interburden, rather than special handle it, provided that the operator undertake a revegetation sampling and analysis program for molybdenum on reclaimed areas (see ch. 3, box 3-C).

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[1] See case study mine C in reference 13.

Figure 5-6.—Example of a Geologic Log

MINE NAME: ______________________ BED: ________ HOLE NO: ________
COUNTY: ______________ STATE: ________ SEC. ________ TWP. ________ RG. ________
DRILLER: ______________________ DATE: ________ EL. ________
Page ______ of ______

Total Ft. & 10ths			Thickness Ft. & 10ths		Sub-sample	Composite sample
0	—	Siltstone, light gray, sandy	10	0		
10	0	Sandstone, very fine grained, yellow, silty, <10% carbonaceous	5	6		
15	6	Shale, light gray-yellow, sandy, limonite stained, <10% carbonaceous	7	1		
22	7	Sandstone, very fine-fine grained, buff, slightly calcareous	2	9		
25	6	Shale, buff-gray, limonite stained, gypsum, <10% carbonaceous	3	9		
29	5	Sandstone, very fine-fine grained tan		2		
29	7	Shale, gray, <10% carbonaceous, limonite stained	4	9		
34	6	Sandstone, very fine grained, tan, slightly calcareous, shaley	5	6		
40	2	Limestone, light gray, <10% carbonaceous	1	2		
41	4	Sandstone, very fine grained, tan, calcareous, <10% carbonaceous, shaley	4	4		
45	8	Shale, gray, sandy, >10% carbonaceous	2	7		
48	5	Carbonaceous shale, w/coal, pyritic		2		
48	7	Shale, gray, sandy, <10% carbonaceous	11	3		
60	0	Sandstone, very fine grained, gray, slightly calcareous, shaley, <10% carbonaceous	21	8		
81	8	Shale, gray, >10% carbonaceous	1	8		
83	6	Sandstone, very fine grained, light gray, shaley, calcareous, <10% carbonaceous	13	3		
96	9	Shale, gray, sandy, <10% carbonaceous	29	6		
126	5	Sandstone, very fine-fine grained, light gray, <10% carbonaceous, w/shale stringers	4	0		
130	5	Shale, gray, sandy	2	0		
132	5	Sandstone, very fine-fine grained, salt & pepper, shaley, <10% carbonaceous	1	0		
133	5	Shale, gray, sandy, <10% carbonaceous	14	2		
147	7	Sandstone, very fine-med. grained, salt & pepper, <10% carbonaceous, shaley	5	4		
153	1	Shale, gray, <10% carbonaceous	1	6		
154	7	Coal, pyritic	1	9		
156	6	Coal	4	0		
160	6	Bone coal		3		
160	9	Coal, pyritic	2	1		
163	0	Carbonaceous shale, w/coal strands		2		
163	2	Coal	1	1		
164	3	Carbonaceous shale		2		
164	5	Coal, pyritic	1	1		
165	6	Carbonaceous shale		1		
165	7	Coal, pyritic	13	7		
179	4	Carbonaceous shale, w/coal, pyritic		2		
179	6	Coal		9		
180	5	Carbonaceous shale		8		

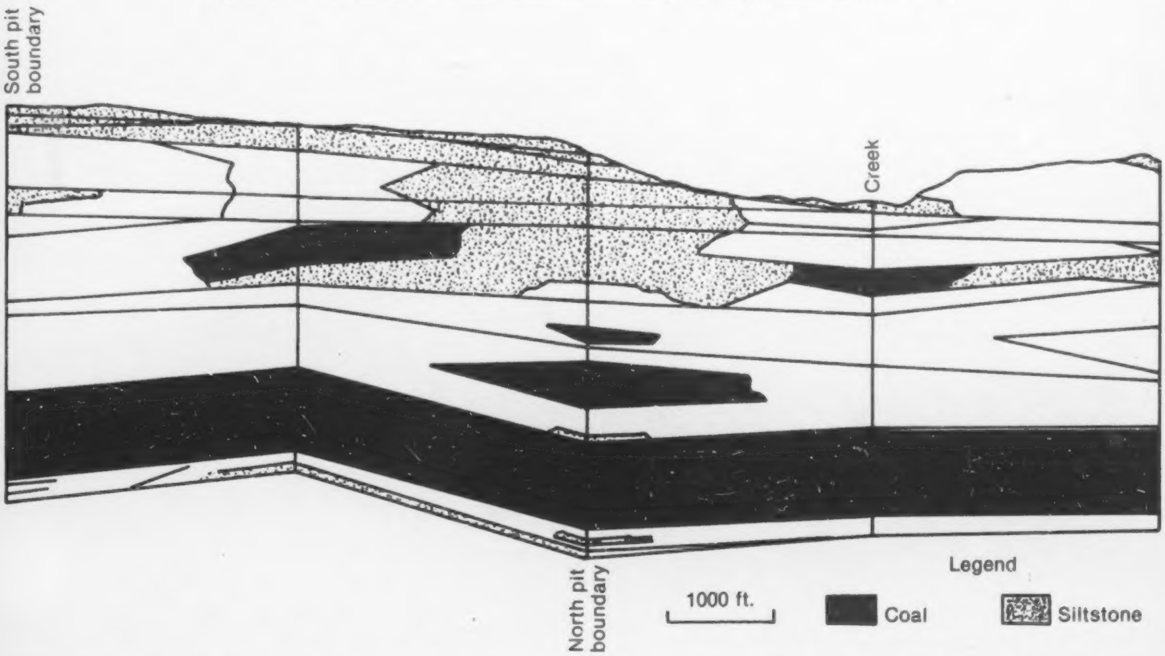
SOURCE: James P. Walsh & Associates, "Soil and Overburden Management in Western Surface Coal Mine Reclamation," contractor report to OTA, August 1985.

gamma radiation, and density as determined from induced neutron radiation. A geologist then attempts to correlate data from the lithologic and geophysical logs across the distance between drillholes and so draw the geologic maps and cross-sections required by most States. The level of detail in these maps is highly variable. Geologic cross-sections usually show topography, coal seam(s) to be mined, easily recognizable overlying strata (e.g., coaly or carbonaceous zones and large sand bodies), and the underlying stratum. Figure 5-7 shows one of the better geologic cross-sections from the permit applications reviewed by OTA.

Samples taken from drillholes are also tested for a variety of geochemical parameters that may adversely effect revegetation and postmining water quality. Typically these include pH, salinity, SAR and/or exchangeable sodium percent, texture, Sat percent, and concentrations of a variety of trace elements such as selenium and boron. Where acid formation in overburden is considered a potential problem, these samples also might be tested for acid-base potential (see ch. 8). Many of the lab tests currently used for these purposes were borrowed directly from soil science, and experience in recent years is calling into question the validity of these tests when applied to overburden. Unlike soils, overburden typically is not oxidized (except in near-surface strata) and so is not in chemical equilibrium with the surface environment. Furthermore, soils are soft and friable and extracts for analysis can be taken readily. Overburden, however, generally is in the form of rock that must be ground before testing, and the amount of grinding affects the test results. Tests designed to extract trace metals from oxidized soil material often do not perform in the same manner when applied to unoxidized overburden. Tests used for nitrates and selenium are particularly suspect as of this writing (see box 5-C). Methods used to test for acid-base potential in overburden are also controversial (see ch. 8).

Soil and overburden monitoring on regraded surfaces is done indirectly, through monitoring

Figure 5-7.—Geologic Cross-Section Showing Stratigraphic Correlations



SOURCE: James P. Walsh & Associates, "Soil and Overburden Management in Western Surface Coal Mine Reclamation," contractor report to OTA, August 1985.

Box 5-C.—Detecting Selenium in Overburden Samples

The current procedure used to detect selenium in overburden samples is a hot-water extraction developed for agricultural soils. In surficial materials, such as soils, selenium is in an oxidized state, readily soluble, and thus easily extracted by this method. Baseline overburden samples, often obtained at considerable depths, are in a reduced condition and the unoxidized selenium compounds are not readily soluble. Therefore, hot-water extraction does not work. The Wyoming Department of Environmental Quality has noted the limitations of this procedure. In one instance, a sample from the Shirley basin known to contain a total selenium value of 410 ppm yielded only 1 ppm in the standard extraction procedure. This appears to explain why selenium has rarely been detected above trace-level concentrations in baseline overburden analyses. While hot-water extraction may not be a valid test for baseline studies, it may still be useful for testing regraded spoils. During the mining and reclamation process, most overburden materials are exposed to the air long enough to become oxidized, particularly in dragline operations where spoils may be unburied for up to a year. Once oxidized, the selenium becomes more soluble, and the hot-water method will work (1).

of water quality and vegetation. None of the five States routinely requires long-term monitoring of normal backfilled spoils or redressed soils, but the regulatory authorities often impose monitoring programs in cases where soil or overburden conditions have been identified as a problem (see the case studies in vol. 2). Types of programs commonly required include: one-time sampling of regraded spoils for unsuitable material in the root zone; one-time or periodic sampling of soils, most often for sodium migration; and monitoring for erosion.

Most monitoring programs require sampling of the surficial spoils (those immediately beneath the soil) only once, immediately prior to topsoiling. If there is little or no change in spoil character over time, one-time sampling may be adequate. However, the extent to which chemical reactions will occur in overburden and the time required for their completion are not well understood. Similarly, the speed and ultimate extent of sodium migration through spoils is difficult to predict. Where sodium has been identified as a potential problem, periodic spoil sampling programs are being carried out. **Without more research on spoil chemistry, the adequacy of current monitoring programs is difficult to assess.**

Moreover, as noted previously, the horizontal and vertical sampling densities for collecting spoils monitoring data are not standardized. At mines reviewed by OTA, data on recontoured spoils were most often based on a grid with samples collected at horizontal intervals varying from 400 to 660 feet (4 to 11 acres/sample).[7] Depth of sampling varied: at two mines, spoil was sampled to 8 feet; at two others, spoil was sampled to 4 feet but at 2-foot intervals. One Wyoming operator proposes to sample on a 625-foot grid (9 acres/sample); if unsuitable material is found in any sample, the surrounding area would be sampled on a 200 foot grid (1 acre/sample). The regulatory authority has not yet acted on this proposal. Another mine is sampling on a 500-foot grid (6 acres/sample). An innovative sampling program is described in box 5-D.

Soil sampling and erosion monitoring programs also vary because they are designed for each individual mine (see box 5-E). At one North Dakota mine, sodium migration and salinity of soils were monitored on a limited basis using research plots.[8] At another mine in Montana, sodium in redressed topsoil over sodic and clayey overburden is being monitored from 20 different sampling locations on the mine-site.[9]

Sampling of spoil in reconstructed aquifers is extremely difficult and so is much less common than sampling of surficial spoil. If there is reason to suspect that deleterious material may be present in the water table, operators may be required to produce samples, but such sampling

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[7] See reference 13, case studies C, E, F, G, H and I.

[8] See reference 13, case study B.

[9] See reference 13, case study D.

Box 5-D.—Innovative Spoil Sampling[1]

One Wyoming mine has developed its own innovative spoil sampling program. Originally, regraded spoils were sampled on a 500-foot grid. Where unsuitable samples were found, the operator sampled in concentric circles around it, but found that due to the high amount of variability in spoil composition, unsuitable areas could not be delineated. The mine soil scientist believes the unsuitable areas are less than 50 feet in radius and generally would not be detected by a 500-foot grid. As a result, a new system has been devised in which "grab samples" are collected from about 10 different locations in a 5-acre parcel. At each location, samples are collected from the intervals 0 to 2 feet and 2 to 4 feet. The intervals are combined from the 10 locations into 2 samples representing the 0- to 2- and 2- to 4-foot intervals for the 5-acre parcel. According to the mine soil scientist, this system takes more time but probably gives a better representation of the recontoured spoil. According to the regulatory authority, such "compositing" has the potential for obscuring small unsuitable areas when unsuitable samples are mixed with suitable samples, and the procedure has not been approved yet.

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[1] See case study mine F in reference 13.

Box 5-E.—Erosion Monitoring

A Montana mine, required by the State to monitor erosion, has developed its own program. Runoff plots have been built both on representative reclaimed, revegetated surfaces and on undisturbed areas. Sediment yield is calculated from total suspended sediment measured in samples of runoff water following rainfall events. According to the mine hydrologist, "fair to good" data have been collected since 1981. The applicant hopes to use a comparison of sediment yield from revegetated areas and undisturbed areas to show that erosion control has been achieved for the purposes of bond release, and possibly to demonstrate that sediment ponds are unnecessary.[1]

A Colorado mine, whose site includes steep slopes, is monitoring erosion using a system developed by BLM, which quantifies soil erosion based on features such as rills, flow patterns, gullies, soil movement and on deposition, the formation of pedestals, and the presence of surface litter (12). The soil erosion is rated as low to severe based on the frequency and size of the observed features. Inspections are made every third year during the bond release period in conjunction with the collection of vegetation data.[2]

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[1] See case study mine D in reference 13.
[2] See case study mine J in reference 13.

is not routine practice. Samples down to about 8 feet can be collected with a truck-mounted auger, but deeper sampling requires use of a drill rig, which can be difficult to stabilize on the uncompacted spoil surface. Even if the rig can be stabilized, samples are not easily recovered because the loose spoil material will not stay in the core barrel. Samples from drillholes also are unpredictable because the uncompacted spoil prevents good circulation of drilling fluids, making it difficult to know the source of the material recovered at the surface. Operators also may collect spoil samples when they sink their wells for monitoring groundwater quality.

The impracticability of spoil aquifer sampling means that operators cannot monitor spoil water quality until the spoils begin to resaturate and leachate begins to appear in monitoring wells. This may not occur until after bond release, raising questions about how any problems appearing at that time will be solved (see ch. 7).

HYDROLOGY[10]

Data Requirements

Requirements for hydrologic data collection are summarized in table 5-3. Wyoming has the most specific guidelines and regulations, followed in order by Montana, Colorado, North Dakota, and New Mexico. The latter two States have not published guidelines, relying on regulations and personal contacts between operators and regulatory personnel to develop hydrologic data collection programs on a mine-specific basis.

Under the Federal and State programs, **surface water baseline studies** must include:

- detailed location of all surface water features;
- streamflow quantity data, including seasonal and annual variations, floods, and low flows;
- streamflow quality data, including both physical and chemical characteristics and the relationship between discharge and quality; relationship between discharge and quality;
- quantification of physical watershed parameters, including topographic features, surficial geology, hydrologic soil types, vegetative cover, and channel and flood plain geometry;
- a description of climatic characteristics that affect surface water hydrology, such as mean annual precipitation, precipitation frequency versus duration relationships, and seasonal and annual variations in precipitation; and
- a description of surface water uses.

Some of this information is in or can be compiled from existing sources of data. For example, information on climatic characteristics may be obtained from the National Weather Service.

Groundwater baseline studies must include:

- location of all groundwater features in the area, including existing wells and springs which may be affected by mining;
- geologic data, such as surficial geologic maps and geologic cross-sections that show: depth and extent of aquifers, confining layers, and hydrologic barriers and boundaries, including any faults or folds;
- static water level data, including seasonal and annual variations, for all affected aquifers sufficient for the construction of potentiometric surface maps to determine flow directions and locate recharge and discharge areas;
- water quality data for all affected aquifers sufficient to determine seasonal and annual variations and suitability of the water for domestic, irrigation, or livestock uses;
- geochemical data for the overburden materials for use in predicting postmining chemical quality of the spoils aquifers;
- results of pump tests to determine: permeability, transmissivity, and storage coefficients for all affected aquifers; effects of hydrologic barriers and boundaries; interaction between aquifers; and interactions between the groundwater and surface water systems.

Alluvial valley floor (AVF) baseline studies must determine whether there are AVFs in or near the proposed permit area, whether an AVF cannot be mined because it is significant to farming, the potential impacts of mining on the AVF, and the prospects for restoring the essential hydrologic functions (EHFs) of the AVF (see chs. 3 and 4).

Federal regulations require that **surface and groundwater monitoring** data be submitted to the regulatory authority every 3 months (19,20). **While quarterly monitoring might be a valuable safeguard of hydrologic resources in the East, it is inappropriate and unnecessary in the West.** In the East, there are many small operators mining in close proximity to one another and the hydrology is highly variable. There, hydrologic impacts may occur rapidly and unpredictably. In a large Western operation, however, a pit may be 4,000 feet long and may only move at a rate of 1,000 ft/yr. Thus, water levels and quality in

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[10] Unless otherwise noted, the material in this section is adapted from reference 15; see also reference 9.

Table 5-3.—Summary of Hydrologic Baseline Data-Collection Requirements by State

Type of data	Colorado (guidelines and regulations)	Montana (guidelines and regulations)	New Mexico (regulations)	North Dakota (regulations)	Wyoming (guidelines and regulations)
Surface water quantity data:					
Perennial	Continuous recording gages. Report max, min, and mean flow.	Continuous recording gages.	Min, max, and avg discharge conditions identifying low flow and peak discharge rates.	Max, min, and avg discharge conditions which identify low flow and peak rates.	Continuous recording gages.
Intermittent	Sample frequency will be dealt with on an individual basis. Determine duration of flow season and peak flow.	Continuous recording gages.	Min, max, and avg discharge conditions identifying low flow and peak discharge rates.	Max, min, and avg discharge conditions which identify low flow and peak rates.	Continuous recording gages.
Ephemeral	Install crest stage recorders. Flow measurement frequency will be dealt with on an individual basis.	Crest stage gages.	Min, max, and avg discharge conditions identifying low flow and peak discharge rates.	Max, min, and avg discharge conditions which identify low flow and peak rates.	Monthly reading of crest gages.
Duration	Not stated.	Not stated.	Not stated.	Not stated. Submit quarterly reports.	Min. of one year of data (see above).
Surface water quality data:					
Parameters	Field: pH, EC, temp, DO Lab: TDS, TSS, Oil and Grease, SAR, HCO3, Ca, Cl, Mg, NO3, NO2, PO4, Na, SO4, Al, As, Cd, Cu, Pb, Mn, Hg, Mo, Se, Zn.	EC, pH, Alk, SAR, TDS, Al, As, Ba, HCO3, B, Cd, Ca, CO3, Cl, Cr, F, Fe, Pb, Mg, Ni, NO3, PO4, K, Se, Ag, Na, SO4, V, Zn.	TDS, TSS, cidity, pH, total and dissolved Fe, total Mn, others as required by the regulatory authority.	TDS, TSS, EC, pH, total Fe, others as required.	Field: pH, temp, EC, chloride, Alk, discharge, turbidity, DO Lab: NH3, NO3, NO2, Al, As, Ba, Cd, Cr, Cu, Fe, Pb, Mn, Hg, Mo, Ni, Se, Zn, HCO3, CO3, Ca, Cl, B, F, Mg, K, Na, SO4, TDS.
Perennial	Field: measure water quality parameters monthly. Complete chemical analysis quarterly.	Quarterly.	Discuss with regulatory authority. Submit quarterly reports.	Discuss with regulatory authority.	Sufficient to characterize quality—discuss with regulatory authority.
Intermittent	Sample frequency will be dealt with on an individual basis.	Quarterly.	Discuss with regulatory authority. Submit quarterly reports.	Discuss with regulatory authority.	Sufficient to characterize quality—discuss with regulatory authority.
Ephemeral	Sample water for complete chemical analysis twice a year, once during snowmelt, and once during a storm event.	When possible.	Discuss with regulatory authority. Submit quarterly reports.	Discuss with regulatory authority.	Sufficient to characterize quality—discuss with regulatory authority.

Table 5-3.—Summary of Hydrologic Baseline Data-Collection Requirements by State—Continued

Type of data	Colorado (guidelines and regulations)	Montana (guidelines and regulations)	New Mexico (regulations)	North Dakota (regulations)	Wyoming (guidelines and regulations)
Springs and seeps	Measure field water quality parameters monthly. Sample water for complete chemical analysis quarterly.	Not stated.	Discuss with regulatory authority. Submit quarterly reports.	Discuss with regulatory authority.	Sufficient to characterize quality—discuss with regulatory authority.
Groundwater quantity data:					
Well Density	None specified.	None specified.	None specified.	Min. 1 data point per aquifer per 4 sq. mi.	Min. 3 data points per affected aquifer per sq. mi.
Pump Tests	Not stated.	Within each affected aquifer.	Not stated.	Not stated.	Within each affected aquifer (2-3 may be adequate).
Methodology Specified? Y/N	No.	No.	No.	No.	No, but some recommendations are made.
Static Water Level Frequency	See water quality sampling frequency.	Monthly for at least one year, one well in each aquifer continuously monitored.	Discuss with the regulatory authority.	Discuss with regulatory authority.	Quarterly.
Potentiometric	Not stated.	For each affected aquifer and next aquifer beneath coal if deemed necessary.	Not stated.	For each affected aquifer and next aquifer beneath coal.	For each affected aquifer.
Groundwater quality data:					
Parameters	Field: pH, EC, Temp Lab: TDS, HCO3, Ca, CO3, Cl, Mg, NH3, NO3, NO2, PO4, Na, SO4, As, Cd, Fe, Mn, Hg, Se, Zn.	EC, pH, Alk, SAR, TDS, Al, As, Ba, HCO3, B, Cd, Ca, CO3, Cl, Cr, F, Fe, Pb, Mg, Ni, NO3, PO4, K, Se, Ag, Na, SO4, V, Zn.	Discuss with the regulatory authority.	TDS, HCO3, Na, Fe, hardness, NO3, SO4, Cl, pH, SAR, Ca, Mg, EC, others as requested.	Field: pH, temp, EC, chlorine, Alk, turbidity Lab: NH3, NO3, NO2, Al, As, Ba, Cd, Cr, Cu, Fe, Pb, Mn, Hg, Mo, Ni, Se, Az, HCO3, CO3, Ca, Cl, B, F, Mg, K, Na, SO4, TDS.
Frequency	Bedrock Aquifers: Field parameters monthly. Complete chemical analysis semiannually. Alluvial Aquifers: Field water quality parameters monhtly. Complete chemical analysis quarterly.	Min. of quarterly.	Discuss with the regulatory authority.	Discuss with regulatory authority.	Sufficient to characterize quality in potentially affected aquifers.

Table 5-3.—Summary of Hydrologic Baseline Data-Collection Requirements by State—Continued

Type of data	Colorado (guidelines and regulations)	Montana (guidelines and regulations)	New Mexico (regulations)	North Dakota (regulations)	Wyoming (guidelines and regulations)
AVF surface water quantity:	Contact the regulatory authority.	Not stated.	Adequate frequencies to indicate long-term trends. Discuss with regulatory authority.	See above.	See above.
AVF surface water quality:	Contact the regulatory authority.	Describe seasonal variations over one full year at a minimum.	Adequate frequencies to indicate long-term trends. Discuss with regulatory authority.	See above.	See above.
AVF groundwater quantity:	Contact the regulatory authority.	Monitoring should be performed at frequencies sufficient to indicate long-term trends. 2 years minimum.	Adequate frequencies to indicate long-term trends. Discuss with regulatory authority.	See above.	See above.
AVF groundwater quality:	Contact the regulatory authority.	Monitoring should be performed at frequencies sufficient to indicate long-term trends. 2 years minimum.	Adequate frequencies to indicate long-term trends. Discuss with regulatory authority.	See above.	See above.

SOURCES: Western Water Consultants, "Hydrologic Technologies for Western Surface Coal Mining," contractor report to OTA, Aug. 1, 1985. Colorado Mined Land Reclamation Division 1982 Guidelines for the collection of baseline water quality and overburden geochemistry data, permit manual, and 1982 Regulations. Montana Department of State Lands 1983 Water Resources Guidelines and Guidelines for the Identification of Alluvial Valley Floors and April 1980 Rules and Regulations. New Mexico Mining and Minerals Division, 1984 Regulations. North Dakota Public Service Commission, Rules Governing the Reclamation of Surface-Mined Land, June 1983. Wyoming Department of Environmental Quality—Land Quality Division Guidelines and October 1984 Rules and Regulations.

monitoring wells offsite are not likely to change rapidly. In addition, as is noted elsewhere in this report, Western regulatory authorities already receive more data than they can review on a regular basis. Instead, they review hydrologic monitoring data when they have to make a decision based on those data (e.g., permit renewal, bond release, or, in Wyoming, annual bond adjustment) or when there is reason to believe some problem exists at a site. As a result, monitoring programs in the West often require semi-annual rather than quarterly monitoring, and operators generally submit these data to the regulatory authorities annually.

Important Sources of Previously Collected Data

The USGS, Environmental Protection Agency (EPA), and the State water offices compile the most commonly used sources of existing hydrologic data available to permit applicants and regulatory authorities in the West (see table 5-4). The USGS's Water Resources Division maintains several excellent data collection networks, including the National Water-Data Exchange (NAWDEX), the National Water-Data Storage and Retrieval System (WATSTORE), and the Index to Water-Data Activities in the Coal Provinces of the United States. NAWDEX indexes data from a nationwide confederation of water-oriented organizations and assists users in identifying and locating water data. WATSTORE digitizes a variety of types of surface and groundwater data collected by USGS at their monitoring stations, including daily values of sediment concentration, stream flow, and reservoir levels; water quality; peak flows; chemical analyses; and geologic data for groundwater stations. The Index to Water-Data Activities indexes available data sources by data type (e.g., streamflow, surface water quality, groundwater quality) for five geographic regions. All of these

Table 5-4.—Primary Sources of Existing Hydrologic Data

Agency	Program	Summary description
U.S. Geological Survey	Annual Water-Data Reports	Records of stage, discharge and quality of streams, stage and contents of lakes and reservoirs, and water levels and quality of groundwater. Published annually by State. Reports available for purchase from NTIS.
U.S. Bureau of Reclamation	Water and Power Management	Reservoir water levels and discharge of streams, rivers and canals. Reports available on request from respective regional office.
U.S. Bureau of Land Management	Energy Mineral Rehabilitation Inventory and Analysis (EMRIA), discontinued	Intended to be a coordinated approach to field data collection, analyses, and interpretation of overburden, water, vegetation and energy resource data in the Western coal field. Data compiled in various EMRIA reports available from U.S. Dept. of the Interior.
U.S. Dept. of Agriculture	Various Programs of the Agricultural Research Service, Forest Service, and Soil Conservation Service	Each agency conducts limited monitoring for specific program needs. Data are available from the respective agency on request.
U.S. Environmental Protection Agency	STORET	Computerized database system for storage and retrieval of data relating to water quality, water quality standards, point sources of pollution, pollution-caused fish-kills, waste-abatement needs, implementation schedules, and other water-quality related information. Any government agency can become a STORET user. The system is accessed by the EPA or by a government agency or university that uses STORET.
National Water Well Association (as part of National Center for Ground Water Research established by EPA through Oklahoma, Oklahoma State and Rice Universities)	National Ground Water Information Center (NGWIC)	Computer retrieval system that searches hydrogeology and water well technology database that resides on a computer at Battelle Columbus Laboratories. Database available to any individual or group upon request or through time-sharing account. Costs assessed for computer time. Geographical coverage is worldwide.

SOURCE: Western Water Consultants, "Hydrologic Technologies for Western Surface Coal Mining," contractor report to OTA, Aug. 1, 1985.

Table 5-5.—Summary of Major USGS Water-Data Management and Acquisition Programs

Program	Description	Accessibility	Geographical coverage
National Water-Data Exchange (NAWDEX)	National confederation of water-oriented organizations aimed at making their data more accessible. Services include assistance in identifying and locating needed water data and referring the requester to the organization that retains the data. Master Water-Data Index (MWDI) identifies sites for which water data are available, type of data available, and information necessary to obtain the data. Water Data Sources Directory (WDSD) identifies organizations that are sources of water data and locations within these organizations from which data may be obtained.	Services available to anyone through USGS National Center and Assistance Centers in 45 states and Puerto Rico. Charges for computer and personnel time and duplicating services.	Nationwide
WATSTORE	Computerized system for processing water data and managing data-releasing activities. Includes the following files: Station-Header File (WRD.STAHDR)—an index of sites for which data are stored in DVFILE, PKFIL, QWFILE, and WRD.UNIT (see below). Daily Value File (DVFILE)—daily values for streamflow, reservoir levels, water-quality parameters, and groundwater levels. Peak Flow File (PKFIL)—annual maximum discharge and gage height values at surface water sites. Water Quality Data File (QWFILE)—results of surface water and groundwater quality analyses. Unit Values File (WRD.UNIT)—water parameters measured more frequently than daily. National Water Use Data System (NWUDS)—a national Federal-State cooperative system designed to collect, store, and disseminate water-use data.	Information available to anyone through any of USGS Water Resources Division's 46 district offices.	Nationwide
Office of Water Data Coordination (OWDC)	Index to Water-Data Activities in Coal Provinces of the United States. Five-volume index to availability of streamflow, surface water and groundwater quality data and hydrologic investigations in the five major coal provinces. Index was derived from the Catalog of Information on Water Data, a computerized information file about water-data activities in the United States.	Individual volumes available for purchase from USGS. Additional information available from NAWDEX Assistance Centers.	Five major coal provinces of the United States

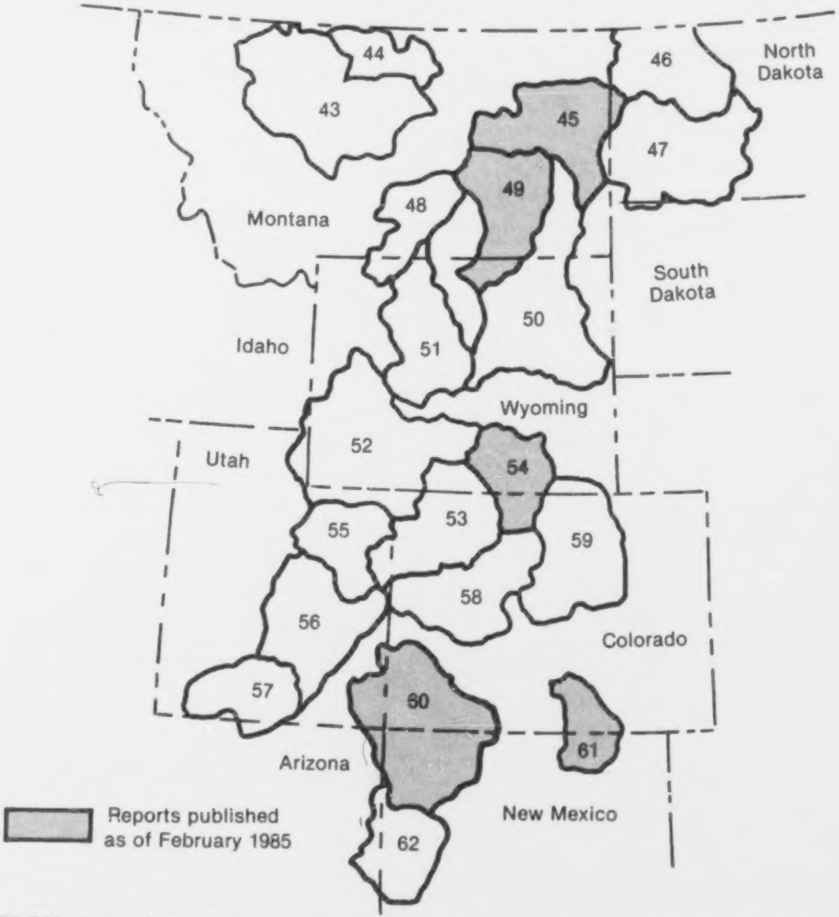
SOURCE: Western Water Consultants, "Hydrologic Technologies for Western Surface Coal Mining," contractor report to OTA, Aug. 1, 1985.

data are available to any individual or organization through the USGS district or national office. Table 5-5 contains additional information on these USGS data management programs.

In addition, the USGS has been compiling a series of reports that describe existing hydrologic conditions and identify sources of hydrologic data in the Nation's coal provinces. These reports are intended to fulfill SMCRA's requirement that an "appropriate Federal or State agency" make "hydrologic information on the general mine area prior to mining" available to permit applicants. The reports also help regulatory authorities judge whether a proposed mining plan adequately "minimizes the disturbances to the prevailing hydrologic balance." Figure 5-8 shows the areas covered by these reports as of February 1985.

EPA maintains a database called STORET that includes water quality data, water quality standards, and point sources of pollution. All govern-

Figure 5-8.—Location Map of Hydrologic Areas for Which USGS Is Preparing Regional Hydrologic Reports


44
43
46
North Dakota
45
47
49
48
Montana
South Dakota
50
51
Idaho
Wyoming
52
Utah
54
53
59
55
58
56
Colorado
57
60
61
Arizona
New Mexico
62
▨ Reports published as of February 1985

SOURCE: Western Water Consultants, "Hydrologic Technologies for Western Surface Coal Mining," contractor report to OTA, Aug. 1, 1985.

ment agencies can become STORET users. EPA also funds and oversees the National Ground Water Information Center (NGWIC), a computerized database of groundwater references operated by the National Well Water Association. Geographical coverage of the database is worldwide. Any individual or group may use the database. Charges are assessed on the basis of computer time used.

Each State in the study region has an office (usually in the State Engineer's office or the State natural resources department) responsible for water appropriation. These offices maintain a centralized system of information on locations of diversion points, names of appropriators, and types of water use. The Montana and New Mexico Bureaus of Mines also have some water quality information. In addition, under the Clean Water Act, each State must maintain a system for classifying streams on the basis of water quality and quantity and suitability for various uses (see ch. 4).

The Wyoming Water Research Center (WWRC) maintains a computerized database of all regularly reported streamflow, groundwater quality, climatological, water well level, and snow course data. The data may be accessed by any individidual or organization who contacts the WWRC office in Laramie. Charges for computer and personnel time are assessed.

The Gillette Area Groundwater Monitoring Organization (GAGMO) is an organization of mine operators in the Powder River basin around Gillette, Wyoming, who measure static water levels in their monitor wells around October 1 of each year and publish the data in annual reports.

Data Collection by Operators

Hydrologic data collection methods and data formats are more standardized than in other disciplines because the methods of hydrologic analysis are more quantitative and increasingly are computerized (see ch. 6). Although this means that the hydrologic data available from outside sources are more extensive and of better quality than is the case in other disciplines, more and better data still are necessary to perform the sophisticated analyses required for permitting. Thus, as in other disciplines, existing data sources may be helpful for initial planning but the vast majority of data still must be collected onsite by the operator.

Moreover, hydrology changes constantly at any given mine site. The mobility of water through the ecosystem makes it impossible to consider hydrology and hydrologic data in the static, site-specific fashion in which soils and overburden data are considered. Consequently, hydrologic data collection that begins as part of baseline analyses usually continues through the life of a mine and becomes part of the hydrologic monitoring of the mine (see fig. 5-1, above). This is true, not just for surface mine reclamation, but for all types of hydrologic work. As a result, hydrologists traditionally have maintained and exchanged data more than in other disciplines. It is worth noting that hydrology is the one area where operators routinely consult previously filed permit applications and occasionally even coordinate and pool monitoring data (e.g., GAGMO).

The bulk of the **surface water baseline data collection** effort goes into streamflow quantity and quality data. Because streamflow characteristics change constantly, data should be collected over sufficient time to delineate the range of natural flows, although additional research may be needed to determine what period of data collection is adequate. Without such long-term streamflow data from several locations along the stream channel, the sophisticated analytical tools described in chapter 6 may not be usable or may yield invalid results.

Compiling flow data for perennial streams is not difficult. Because perennial streams are relatively uncommon in the West, they already are monitored closely, often by the USGS. Depending on the positions of these monitoring stations relative to the mine site, these data may be useful to permit applicants. If no preexisting data are available on a perennial stream at a particular site, gaging technology to collect flow data is well developed and standardized. Operators usually install water level recorders at selected points along perennial streams; these provide continuous data on both water levels and flow rates. Water sampling for water quality analyses, particularly of sediment levels, also can be done at any time.

However, most streams in the West are ephemeral or intermittent and flow only occasionally—after precipitation or spring snowmelt events and, in the case of intermittent streams, when the water table is high. Opportunities for collecting data and samples may be few and far between for these streams, and they are less likely to be the objects of previous data collection efforts. Moreover, compiling reliable flow data for ephemeral and intermittent streams in the West is difficult because the crest-stage gages usually used to measure flows in these channels only record the highest water surface elevations reached since the last gage reading; they do not indicate flow rate or how fast water levels rose or receded when the flow event occurred. Flume gages equipped with water level recorders are more sophisticated methods of collecting flow data. They record how fast water rises in the channel and how fast it recedes using automatic recording devices activated by water flow. They are also about 100 times as expensive as crest-stage gages and are likely to be washed out or damaged during major runoff events.

Obtaining water quality samples from ephemeral and intermittent streams also is difficult. First, having personnel at each channel at the time of peak flow during each flow event is impracticable and sometimes dangerous. Second, and also a problem at perennial streams, the methodology to be used for taking samples has not been standardized, and different sampling methods can add significant variability to water quality data. Even the USGS has not formulated a standard procedure for how and where in the flow water quality samples should be taken. Third, water quality data are meaningful only if accompanied by data on flow rate and volume at the time of sampling. As noted above, simple crest-stage gages do not provide these data.

Obstacles to collecting reliable surface water data for ephemeral and intermittent streams often leave Western operators with insufficient data for detailed reclamation planning. At one Wyoming mine, only 33 data points were available on which to base the reclamation plan. At another, only three samples from seven sampling sites were collected. A third Wyoming mine installed five crest-gages in 1978, but only one flow event has been recorded at three of the gages; none at the other two. A Colorado operator had no data available on flow or quality of ephemeral streams despite two gages on the site. No New Mexico mine reviewed was able to collect enough data on ephemeral streams to plan reclamation adequately. To compensate for this lack of surface water data, operators have turned to other methods of calculating peak and low flows based on the topography, soils, vegetation, precipitation and land use of the drainage (see ch. 6).

Necessary geologic and geochemical data for **groundwater baseline studies** usually are obtained from the overburden baseline studies described above. Permit applications from adjacent mines also may be a good source of geologic information for a permit applicant. All other data are collected with a series of observation wells drilled by the operator for this purpose. These wells are drilled with an imperfect knowledge of the subsurface hydrogeology and therefore rarely yield complete data for hydrologic modeling and construction of potentiometric surface maps. Wells must be drilled carefully so that only pertinent aquifers are open to them and all other water sources sealed off. **Since 1980, both well drilling and sampling techniques have improved and the quality of groundwater data has improved correspondingly. Efforts to coordinate data collection, such as the GAGMO agreement, could add to the utility of groundwater data.**

A variety of data are taken from these wells. Water levels are monitored regularly and are used to prepare potentiometric surface maps showing the static water level of an aquifer at a given point in time. Data on the storage and transmission properties of pertinent aquifers also are collected, usually with a pump test. By pumping water from the aquifer at a constant rate or in a series of stepped rates and measuring the change in water level, data on transmissivity and storativity of an aquifer can be calculated.[11] The calculation requires assumptions, however, about both the homogeneity, the extent, and the thickness of the aquifer, and it is accurate only to the extent that the assumptions are valid.

Water quality data also are collected from samples taken from observation wells. Standard or recommended practices exist for taking most of these types of samples, as well as for the handling and preservation of water quality samples. Some parameters such as acidity/alkalinity, specific conductivity, and pH change rapidly and should be measured in the field; other measures can be taken from laboratory samples. EPA and others have published guidelines for preservation and laboratory analysis of samples for suspended and dissolved solids, minerals, and other tests that may be prescribed in the regulatory programs.

Temporal and areal distribution is an important consideration in groundwater data collection. Ideally, baseline data are collected from enough wells and over a sufficient time period to allow determination of the natural spatial variations in aquifer permeability (saturated hydraulic conductivity), and of the spatial and temporal variations in static water levels and water quality. Spatial distribution of data is usually not a problem for Western operators, but some problems have arisen regarding temporal distribution.[12] For example, data for a potentiometric surface map must be taken as close to simultaneously as possible. This is particularly important in active mining areas where water levels may change substantially over time, and in shallow, unconfined aquifers where water levels change significantly with season and with precipitation and runoff events.

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[11] "Transmissivity" is the rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient. "Storativity" is the volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head.

[12] Note, however, that State requirements for spatial distribution of groundwater data vary considerably; see table 5-2.

Identification of an AVF requires an integration of geologic, hydrologic, and agricultural land use data. Identification usually begins with a preliminary surficial geologic map, if available from the USGS, from which a rough estimate of the areal extent of streamlaid deposits—the geologic sign of an AVF—can be made. This estimate is then refined using surficial geologic maps prepared by the operator from topographic maps, stereo-paired aerial photos, and site inspection. After the areal extent of the AVF is delineated, land use is determined from county land offices and land owners to see if the prohibition against mining AVFs significant to agriculture would apply.

If the area can be mined, detailed studies are conducted to identify the essential hydrologic functions of the AVF and provide a plan for their restoration. Many of these studies are similar to those described previously for surface water and groundwater baseline studies. Data collected include:

- site geomorphology and watershed characteristics, including drainage basin parameters, streamflow characteristics and channel and flood plain geometry;
- hydrogeological characteristics of the AVF, including thickness, lithology and areal extent of the alluvial deposits; aquifer hydraulic characteristics including saturated thickness, transmissivity, storativity, flow rates, and directions of flow in the alluvial aquifer and in hydraulically connected bedrock aquifers;
- water quality characteristics of the surface water and alluvial and bedrock aquifers; and
- presence and extent of subirrigation, including installation of water level recorders on alluvial wells to determine diurnal water level fluctuations (this information, together with information on porosity and areal extent of the alluvial aquifer, can be used to quantify the amount of groundwater transpired by plants during daylight hours).

Hydrologic monitoring data are collected as a continuation of baseline studies with the same methods and equipment. The many dynamic features of a mine site's hydrologic regime mean that operators must collect data continually throughout the life of the mine. Therefore, a vast quantity of hydrologic data, particularly groundwater data, is being amassed. Regulatory authorities receive so much hydrologic monitoring data that often their personnel cannot review and analyze all, or even most, of it. None of the regulatory authorities has the time or the resources to evaluate hydrologic data from a regional perspective to test for anomalies or inconsistencies, and erroneous data could remain undetected for years. At one mine reviewed by OTA, improperly reduced crest-stage data were submitted to the regulatory authority for 2 years before the errors were detected.[13]

Ideally, operators analyze and use hydrologic monitoring data during reclamation and in evaluating reclamation success. In at least one case reviewed by OTA, an operator has organized and uses a very large amount of hydrologic data (see box 5-F). Often, however, hydrologic monitoring is perfunctory. Operators collect large amounts of data at considerable expense and submit them to the regulatory authority to satisfy monitoring requirements, and the data are not used again unless questions or problems arise. One obstacle is format. There are no uniform procedures for filing monitoring data, and most such data reside in boxes in regulatory authority offices. They rarely are published, or even indexed, and accessing them is extremely difficult and time-consuming. From the standpoint of hydrologic data, and particularly groundwater data, the ability to access and manage the vast amount of data available is much more of an issue than any gap in the data.

Steps are being taken in some areas to improve the accessibility and reporting of hydrologic mon-

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[13] See reference 15, case study 3.13.

Box 5-F.—Managing a Large Hydrologic Database[1]

All Western mines are collecting a great deal of hydrologic data. For large operations that have been monitoring for many years, however, the size of the accumulated hydrologic database can be very large. At one such mine in the Powder River basin, the operator has created a hydrologic resource library to manage all of the hydrologic baseline and monitoring data. In addition, the library incorporates data collected by the various agencies that have investigated hydrologic facets of the mine operation over the years. In the library, hydrologic data are sorted into volumes on: streamflow quality and quantity; groundwater elevations in monitoring wells; groundwater analyses including computer-plotted hydrographs and aquifer test results for monitoring wells; lithologic logs of observation wells; and well development data. Hydrologic resource reports compile annual and interim reports of monitoring data submitted to the State regulatory authority, and correspondence relating to hydrologic issues. The hydrologic resource reports also include copies of published and unpublished hydrologic studies pertinent to the mine operation, usually conducted outside routine monitoring and analysis. These studies cover such topics as AVF characteristics, selective placement of overburden, waters impounded on mine spoils, and postmining spoil water quality. The library is updated periodically and updated copies are maintained in the State regulatory authority's office.

The operator's purpose in developing this library was to facilitate both in-house and regulatory use and review of a very large database. Inhouse, the library is valuable to the operator's in preparing permit applications for mine expansion; it reduces duplication of data in those applications by referencing data previously submitted to the regulatory authority. This referencing, however, means that the permit application cannot stand on its own, but must be reviewed in conjunction with the hydrologic library. Mine company personnel report that the regulatory authority has on occasion expressed confusion about these references. However, as the regulatory authority becomes more familiar with the use and periodic revision of the library, it is likely that much of this confusion will cease.

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[1] See case study mine G in reference 15.

itoring data. One excellent example is GAGMO. In addition, the Montana Bureau of Mines and Geology has submitted a proposal to the State to collect all the available hydrologic data submitted by mining companies, evaluate it, and prepare a computerized database to make the data manageable and readily available to interested persons (8). It is not known when and if this project will be funded. The State of Wyoming recently announced plans to place all the groundwater data from the DEQ files into the State's computerized information search and retrieval system (16). This project is expected to take 2 years or more due to the vast amount of data on file (17).

REVEGETATION[14]

Data Requirements

Requirements for collection of baseline vegetation data vary with land use. Most State regulations and guidelines focus on data collection on rangeland (by far the most extensive land use in the study area), but include alternate data collection requirements for other land uses such as wildlife habitat or pastureland. Table 5-6 summarizes requirements and accepted procedures for baseline data collection in each of the five States.

All five States require vegetation maps for all land uses. Scales for vegetation maps range from 1 inch equals 400 feet in Montana and North Dakota, to 1 inch equals 2,000 feet in Colorado. Most permit applications reviewed for this assess-

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[14] Unless otherwise noted, the material in this section is adapted from reference 14.

Table 5-6.—Selected Current Requirements for Vegetation Baseline Data by State

	Colorado	Montana	New Mexico	North Dakota	Wyoming
Vegetation mapping	Required in all States				
Range sites		R	Z	R[f]	
Vegetation types	R	R	R	R[g]	R
Scale	R,1″=2000′ X,1″=500′	R,1″=400′ for veg type map	X,1″=500′	R,1″=400′ for both maps	X,1″=400′-700′
Cover data	Required in all States for native rangeland and wildlife habitat and in ND for tame pastureland				
Absolute cover	R	R	R	R	R
Relative cover	Z	X		Z	X
Quadrat estimation	Z	X	X		X
cover classes	Z	Z	Z	Z[g]	Z
by percent	Z	X	Z		Z
Line intercept	Z[a]	X[c]	Z		X[a]
Point intercept	Z		Z	Z	X
Production	Required in all States for native rangeland, cropland, and pastureland				
Herbaceous	R	R[d]	R	R	R
Woody	X[b]	R	X[e]		
Clipping	X	R	X	X	X
Quadrat size	variable	X,0.5 m^2	variable	Z,often 0.25 m^2	Z,0.5 m^2
Doubling sampling	Z		Z	Z	
Shrub density	Required in all States for wildlife habitat and in CO, MT, NM and WY for native rangeland				
Shrubs	R	R	R	R[g]	R
Subshrubs		R	R	R[g]	X
Quadrats & belt transects	X	X	X	Z[g]	X
Plotless samples	Z				
Diversity	All States require collection of data that can be used to calculate species/lifeform diversity for native rangeland and wildlife habitat.				

Key to symbols and superscripts

Symbols

R, written requirement by State regulatory authority, i.e., law, rule or regulation.

X, preferred or recommended by State regulatory authority, i.e., written guideline or unwritten but clear preference. In the case of written guidelines (MT and WY), the guidelines are usually treated as requirements by the coal companies.

Z, not specified but in fact accepted by the State regulatory authority.

Superscripts

[a] for shrubs only
[b] when also wildlife habitat
[c] for trees and shrubs only
[d] by lifeforms only
[e] for palatable species only
[f] for native grassland only
[g] for woodland or wildlife habitat only

SOURCE: Western Resource Development Corp. and Dr. Jane Bunin, "Revegetation Technology and Issues at Western Surface Coal Mines," contractor report to OTA, September 1985.

ment used the more detailed scales of 1 inch equals 400 feet or 1 inch equals 500 feet. In each State except North Dakota, vegetation maps must show actual premining vegetation types; North Dakota requires such maps for woodland and wildlife habitat only.

Montana, New Mexico, and North Dakota also require "range site" maps as part of baseline vegetation studies. These are based on SCS range site descriptions of the species composition and production of vegetation that *could* develop for a given soil type and climatic regime, free of disturbances such as fires and heavy grazing pressure. Thus, range sites describe potential or "climax" vegetation rather than existing conditions. On poorly managed or overgrazed lands, actual vegetation communities may bear little resemblance to the potential vegetation of range site descriptions. Table 5-7 shows that only the northern two States commonly use range sites, and only North Dakota relies on them exclusively.[15]

All five States require baseline data on annual production of above-ground biomass on the mine site for at least some land uses. Baseline production data are broken down according to plant

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[15] Range site data also tend to be best on agricultural lands, which are more common in North Dakota than in any of the other four States.

Table 5-7.—Native Rangeland and Wildlife Habitat Vegetation Data Present in Permit Applications Reviewed by OTA

Data shown were present in permit applications on file at OSM and do not necessarily reflect correspondence between the coal company and regulatory authority (RA) that followed submission of the application; that is, whether the RA required additions or changes, and whether the proposed performance standard was acceptable to the RA.

	Montana	Wyoming	Colorado	New Mexico	North Dakota	Total
Number of permit applications reviewed	7	36	21	10	7	81
Study dates[a]	77-81, one 74	most 78-82	most 79-83	most 80 & later	79-81	
Work by						
consultants	4	29	19	4	2	
company personnel	2	6	1	3	1	
combination	1	—	—	2	2	
SCS data only	—	1	1	—	—	
unspecified	—	—	—	1	2	
Veg map units						
range site	7	7[e]	2	1	7	
veg types	7	29	18	9	1[g]	
ecological response unit	—	—	1	—	—	
Map scales						
1"=400	6	Most 400,500 up to 2,000	Most 400,500 up to 2,000		7	
1"=500	1			200-2,000		
Cover sampling method						
quadrat	7	17	5	3	1[g]	
point transect	—	16	7	2	1	
point frame	1 (& quadt)	2	6	—	5	
line intercept	4[b]	7[b]	5[b] 2 & herbs	1[b] 5 & herbs	—	
none		1[f]	1[f]			
Cover reported as						
absolute cover	7	35	20	10	7	
relative cover	—	13	5	2	3	
Frequency data	7	18	9	8	7	
Production						
by clipping	7	35	20	9	6	
by double sampling	—	3[b]	—	—	2	
SCS data	—	1[f]	1[f]	—	—	
none	—	—	—	1	1[g]	
Woody plants[c]						
density reported	6	28	17	10	1[h]	
shrub heights (inches)	1	24	5	—	—	
Species diversity calculated[c]						
species richness	—	7	2	—	1	
numerical index	1	10	13	1	—	
both	—	2	—	—	—	
Success standard[d]						
reference area	5	5	15	5	4	
control area	—	24	2	—	—	
unspecified comparison area	1	2	—	—	—	
unadjusted baseline	—	—	1	—	—	
historical record	—	—	—	3	—	
technical standard	—	—	—	—	3[i]	
ambiguous or unspecified	1	5	3	2	—	

[a] usually 1 year of data except for NM
[b] for shrubs only
[c] as reported in permit application; not shown here are data submitted subsequently and found in correspondence files
[d] acceptability to regulatory authority not shown
[e] mostly coal companies
[f] only SCS data used; premine vegetation no longer present
[g] for woody draws
[h] only one permit application included vegetation that has a measurable number of woody plants
[i] in one case, the standard was for postmine land uses of hayland/pastureland for property that was premine native rangeland

SOURCE: Western Resource Development Corp. and Dr. Jane Bunin, "Revegetation Technology and Issues at Western Surface Coal Mines," contractor report to OTA, September 1985.

species morphology. Montana requires production data for both herbaceous and woody species; Colorado and New Mexico require data on herbaceous species and recommend collection of woody species data; North Dakota and Wyoming require production data for herbaceous species only. In New Mexico and North Dakota, operators need not collect production data for land whose primary use is wildlife habitat, and production data for croplands usually are based on yields reported by the rancher or farmer. All five States require or recommend at least some production data by direct clipping and weighing rather than by the "double sampling" method, which is faster but the results are of variable accuracy (see below).

Cover data describe the area of ground covered by the aerial parts of plants. Because cover indicates the probability that a falling raindrop will hit something besides bare soil, these data are closely tied to erosion control. "Absolute cover" is the actual percentage of ground shielded by each plant species and may be greater than 100 percent where plant canopies overlap. "Relative cover" is the percentage of the total vegetative cover contributed by each species and must total 100 percent by definition. All five States require absolute cover data and Montana and Wyoming both recommend submission of relative cover data. Cover data are required for all native vegetation types (i.e., native rangeland and wildlife habitat), but are not required for cropland in any of the five States, and are required for pastureland only in North Dakota.

Woody plants are particularly important as cover and forage for wildlife habitat; for this reason data on woody shrub density are required for all wildlife habitat lands, and on native rangeland in four of the five States. The lack of shrub density requirements in North Dakota reflects the paucity of upland shrubs in that State. Woody plant data are obviously not pertinent to pastureland or cropland and are not required for these land uses. Woody plant density baseline data have become less important as more operators negotiate standards independent of precise premining levels. As discussed in chapter 8, this practice recognizes that the premining shrub densities may be either artificially high or low.

Vegetation diversity may be calculated by species, lifeform (the particular morphologic category of a species such as tree, shrub, grass, or subdivisions of these categories), or seasonality (the time of year when a plant accomplishes most of its growth), and may be based on either cover or production data. Differences among plant species or lifeforms over a landscape provide another measure of diversity.[16]

Four States in the study area currently require revegetation monitoring, but the data usually do not have to be submitted to the regulatory authority until final evaluation of revegetation success. Colorado, the only State currently without a revegetation monitoring requirement, is now in the process of revising its regulations to require periodic submittal of quantitative monitoring data. This will make Colorado's requirements the most stringent, because the other four States do not specify that the revegetation monitoring data must be quantitative.

Important Sources of Previously Collected Data

Fewer site-specific sources of data exist for vegetation (and wildlife) than for soils, overburden and hydrology. Where vegetation data are available, they often are of limited use to operators. The areal extent, intensity, and quality of existing data usually are not adequate for permit application requirements. In addition, as discussed below, the variation in data collection methods used by vegetation specialists makes data from different sources difficult to integrate.

SCS compiles maps of vegetation classified by range site. These maps are useful to land management agencies such as BLM and the U.S. Forest Service (USFS) in establishing the carrying capacity of land, and can give a permit applicant a preliminary idea of the types of vegetation on the site. Their usefulness for permitting is limited, however, because: 1) they describe composition and production only of the best vegetation available in the area; 2) the specific data used to compile the general description of the range site probably came not from the mine site but from some vegetatively similar area, so that while the species composition and species dominance of the mine-site may be similar to that of the range site description, cover and production values may be very different; 3) the map scales typically are not detailed enough to meet the requirements for permit applications; and 4) range site data may not be available for areas without agricultural importance, such as woody draws. In addition, as noted earlier, vegetation at mine sites is rarely of the high quality described in SCS range sites because of the ubiquitous disturbance from livestock grazing and other sources in the West.

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[16] See reference 14 for a more detailed discussion of the various ways diversity may be calculated.

The SCS data are now being entered into a computerized database in Fort Worth, Texas, called the National Range Database. Besides SCS, the principal users of the data are other Federal range management agencies, and range science faculty and students at State universities.

BLM and USFS both collect vegetation data that are more representative of actual conditions than the range sites described by SCS data. BLM data use production and frequency of occurrence as indices of cover and species composition. However, the vegetation being sampled usually has been grazed, and production data typically represent only some fraction of the total possible production. Moreover, the BLM and USFS data are not always collected by experienced personnel, as SCS data are. Nevertheless, because BLM lands often coincide with potential coal development areas, these data can be useful to operators.

All of these federally collected data, while useful for large-scale range management, generally are neither intensive nor objective enough for permit application packages. Researchers in plant ecology and range science also have collected vegetation data using more sophisticated methods that are both more objective (repeatable) and more statistically reliable. These data are not well-distributed geographically, but are concentrated in areas near major universities or their research facilities, or sites of some special interest. Furthermore, the quantitative techniques used, although generally more intensive and objective than range management methods, are far from uniform and thus of limited value for comparing and combining with other data.

Data Collection by Operators

Because vegetation data sources are of limited usefulness, virtually all **baseline vegetation data** must be collected onsite. Since about 1979, vegetation data have been collected under strict statistical constraints and, to a lesser extent, narrow methodological guidelines established by State or Federal regulatory authorities. The statistical and methodological requirements vary among jurisdictions and have varied over time within jurisdictions since 1979. In the study area, there is more than one accepted methodology for collecting data for almost every required vegetation parameter.

Production is almost always determined by clipping, except on agricultural lands, when it is determined by crop yield. All above-ground plant material is clipped within circular or rectangular plots and sorted by species or lifeform. The clipped materials usually are oven-dried and weighed. These values are then used to estimate production per unit area of each mapping unit for each species or lifeform group. This may be expressed in pounds per acre, grams per square meter, or some other unit.

Double sampling also can be used to measure production. In double sampling, vegetation production is estimated visually in all plots, with clipping conducted in a few of the plots to calibrate the visual estimates. Although the accuracy of this method is highly dependent on the sampler, it is faster than the harvest method. It is accepted by all regulatory authorities in various carefully prescribed forms, but rarely has been used in baseline studies.

Two variables affect production data. First, inclusion of shrubs or annual plants affects the production values. Second, variations arise from the seasonality of plant species because production is usually estimated at a single time—presumably the time of maximum standing crop. In much of the study area, the differing times of peak production of the dominant species will cause measured production to be low by an unknown and variable amount.

Cover can be measured in three ways. It can be estimated visually in quadrats (small plots), which are usually on the order of one square meter or less. Subdivisions within the quadrat aid in making the visual estimates. The estimate of cover is then expressed by percent or by cover classes representing a specified range of percentage values. This method may be fairly consistent if the same observer makes all estimates, but variability between observers is to be expected and may be quite large. Second, cover can be estimated by line intercepts, which are somewhat more objective than quadrats. In this method, the portion of a tape (often 30 meters in length) intersected by the aerial parts of each species is recorded. Cover also may be estimated by a point intercept method in which plants are recorded when "hit" by the downward projection of a point, either defined by cross-hairs in a viewing device or by pins suspended in a rectangular frame. Although objectivity and repeatability are theoretically greater in point-intercept sampling, in practice these advantages commonly are reduced substantially by nonrigid point placement or projection and by the slowness of the method. Table 5-7, above, shows that use of the line intercept method is mostly confined to shrub cover data, and that there is a fairly equal spread of use among the quadrat and point intercept methods.

Woody plant density may be measured either by counting all individuals by species within large quadrats or narrow belts, or by plotless methods such as measuring the distance from a number of points to the nearest shrub or tree. Methods may or may not include subshrubs or semishrubs (which are smaller and/or woody only at their bases), depending on the States' regulations or guidelines. Direct counts of all woody plants, including semi- and subshrubs, within large quadrats or belt transects provide the most reliable data. Unfortunately, over 25 percent of approximately 60 mines surveyed by OTA have used very small quadrats or dimensionless samples.

Revegetation monitoring data generally are collected with the same procedures and for the same parameters as baseline data, and are intended to demonstrate compliance with the SMCRA performance standards (see ch. 7). Most coal companies collect at least some revegetation monitoring data, illustrating wide acceptance of the need for tracking the progress of revegetation. Careful monitoring can help operators to recognize problems and modify methods to improve revegetation results. Monitoring data also can be used to adjust livestock stocking rates and to evaluate the successional progress of postmining plant communities.

The States do not require submittal of revegetation monitoring data prior to the 2 years preceding final bond release, although some operators do so voluntarily. As a result, few revegetation monitoring data are available publicly beyond the individual mines. Thus, unlike hydrology and other disciplines, there is not a rapidly growing pool of revegetation data in the public domain, and there is little communication among operators and regulatory authorities about the relative success of various revegetation techniques. The regulatory authorities are concerned that they will not know whether the revegetation standards can be met until the bond release period nears its end on a number of mines. If operators did file their revegetation monitoring data in a specified format with the State regulatory authority, the advance warning of potential revegetation problems might increase the chance of finding mutually acceptable solutions at an early stage and so prevent larger problems in the long run.

WILDLIFE[17]

Data Requirements

All five States require wildlife studies for species that are known from existing information (e.g., an EIS or other regional studies) to occur in the area of the mine site or that are likely to occur due to available habitat on the site. Table 5-8 provides a comparative summary of State baseline data requirements for each of these species studies. For each type of study, a State may list a range of acceptable data collection techniques (see table 5-9). All States except New

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[17] Unless otherwise indicated, the material in this section is based on reference 3.

Table 5-8.—State Wildlife Baseline Data Requirements

North Dakota	Montana	Wyoming	Colorado	New Mexico
Guidelines:				
State legislature does not allow use of formal written guidelines. All formal requirements must go through formal rulemaking process. PSC uses technical memoranda instead.	Has formal written guidelines, but these are currently being revised. These provide general info on objective, intensity, duration of baseline studies, but no detail info about methodologies.	Has formal written guidelines which provide general info on baseline data collection requirements, and specific info on required and acceptable methodologies. Stress that guidelines not mandatory, but deviations must be approved by Dept, if Game and Fish. Also stress that not all requirements are necessary for all operations and that operators can use existing data collected on adjacent sites. There are also separate guidelines for raptor nest surveys.	Has draft, informal guidelines available on request. These identify pertinent data sources and contain general info on baseline data collection. Specific data collection techniques are not discussed.	Has no formal written guidelines but intends to develop these in the future.
Emphasis of required studies:				
Limited extent of habitat means that greatest emphasis is on woody draws, wetlands, and native prairie. State stresses need for habitat descriptions and mapping.	Species occurence, seasonal occurence, relative population densities of ecologically important species. Also classification, delineation, and species utilization of habitats.	Distribution, relative abundance and habitat affinity of game species, State sensitive species, raptors, and T&E species stressed. Habitat classification, delineation and mapping (both veg and physical characteristics) also emphasized.	Delineation and mapping of habitat including special habitat features. Also, mapping of species use of habitats by game, species with stenotopic habitat requirements, State sensitive and T&E species.	Characterization of premine habitat conditions and quantitative data for all species groups, particularly those felt to be in greatest jeopardy from disturbance.
Required studies:				
Fairly standard for each different species present. Mines must complete site-specific studies; data from adjacent areas cannot be substituted.	Required on a case-by-case basis, with attention to old guidelines. DSL must approve all study designs.	Studies required on case-by-case basis in consultation with DEQ and Dept. of Game and Fish. A list of acceptable data collection techniques by species group is published.	Studies required on case-by-case basis in consultation with MLRD and DOW. A list of acceptable data collection techniques has been published.	Studies required on case-by-case basis in consultation with MMD and State Game and Fish. A list of acceptable data collection techniques has been published.
Duration, intensity & regionality of data collection:				
One year (four seasons) of data collection required. Studies must cover site plus one-mile buffer zone around site.	One year (four seasons) of data collection required (two winter seasons preferred). DSL requires minimum of one field biologist on-site for 1 year for large operations not previously studied. Studies usually must cover site plus two-mile buffer zone. If unique habitats found, must assess extent of these on adjacent lands.	One year (four seasons) data collection required. Seasonal studies vary depending on species group. Studies must cover site plus two-mile buffer. PRB pronghorn study is an exception, a regional study. Some raptor studies also extend outside area boundaries.	One year (four seasons) data collection required. Seasonal studies vary depending on species group. Studies must cover site plus 0.25 miles beyond permit boundary. Only two instances of required studies beyond permit area: elk telemetry study and sage grouse study in North Park.	One year (four seasons) data collection required. Seasonal studies vary depending on species group. Requirement of studies beyond site-specific depend on potential impacts and species to be impacted.

Table 5-8.—State Wildlife Baseline Data Requirements—Continued

North Dakota	Montana	Wyoming	Colorado	New Mexico
Data format and availability:				
Data are submitted in permit applications, on file with PSC and OSM. PSC has compiled some data in their files.	Baseline data submitted in permit applications to DSL and OSM. Annual monitoring reports also submitted to DSL and OSM. Dept. of Fish, Wildlife, and Parks occasionally incorporates some data into its reports. FWS maintains limited compilation of raptor data. Otherwise, no systematic compilation or clearinghouse for data.	Data are submitted in permit applications and annual monitoring reports to DEQ and OSM. Dept. of Game and Fish was compiling game, furbearing, State sensitive and T&E species data into regional wildlife resource maps for State, but these not updated since 1981. Game and Fish encourages use of its standard observation form so wildlife info can be easily entered into Game and Fish computers, but forms not always used.	Data are submitted in permit applications and annual monitoring reports to OSM and MLRD. DOW occasionally uses data to update its Wildlife Habitat Inventory System, a computerized data bank of wildlife habitat and geographic info.	Data available only in permit applications filed with MMD and OSM. MMD hopes to compile a database in future.
Users of data:				
Beyond PSC, there is little review or use by others.	In addition to DSL, and occasionally DFWP and FWS, some consultants may use data from adjacent mines to develop wildlife info for their clients' mines.	Occasionally, operators from adjacent mines will use data, but not often. FWS compiles all raptor data; available in FWS files.	Aside from OSM, MLRD and DOW review, data rarely used. Colorado Nature Conservancy has reviewed some data on T&E and State sensitive species. Also, a State, Federal and university project to model shale oil development effects on wildlife using some of these data.	Aside from MMD, Game and Fish and FWS, who review data for permit issuance, data used only occasionally by environmental groups.
Required monitoring:				
Monitoring is not uniformly required. Currently formulated on case-by-case basis.	Monitoring using methods similar to baseline data collection methods is required until reclamation considered complete. Aerial surveys once a month and 100 days per year are required.	None specifically required. When it is done, is usually initiated by operator, in consultation with Game and Fish, to address specific concerns and help demonstrate success.	None specifically required, except on case-by-case basis.	None specifically required, except on case-by-case basis in consultation with MMD and Game and Fish.
Evolution of data requirements since 1977:				
State has moved away from strictly counting species and numbers, and has placed more emphasis on habitat descriptions, mapping, and eventual habitat replacement.	More organized and consistent, more tailored toward individual cases and unique info needs. More emphasis on premining data collection to develop success criteria.	Less species inventories, population estimates. More habitat description and delineation. Fewer data required on nongame and nonlegal species, especially where data available from adjacent mines with similar habitats.	State has always emphasized habitat delineation and mapping. Has de-emphasized collection of nongame and other info not used for impact assessment.	Used to be concerned with only those species with "consumptive" value. Now view all species as important, as reflected in data collection requirements.

SOURCE: Cedar Creek Associates, "Wildlife Technologies for Western Surface Coal Mining," contractor report to OTA, August 1985.

Table 5-9.—Accepted Data Collection Techniques[a]

Study category	North Dakota	Montana	Wyoming	Colorado	New Mexico
Big game	Aerial survey—late winter	Aerial surveys—2 per month Browse transects Scat and stomach examination	Aerial and ground surveys—late winter, summer, late fall	Aerial and ground surveys—winter, late spring Pellet group and browse surveys	Aerial surveys (2)—spring and fall
Furbearers	Trapping only in woodlands—fall	Incidental observations	Incidental observations	Incidental observations	Spotlight surveys—all seasons Systematic observation of scat and tracks—all seasons
Small mammals	Trapping only in woodlands—fall	Live and snap trapping—spring and fall [grid trapping preferred in all habitats including reclaimed and undisturbed (control) habitats]	Live and snap trapping—late spring or summer (transects, grids, or clusters depending on habitat)	Live and snap trapping—late spring or summer (transects)	Live and snap trapping in all habitats—spring and fall Voucher specimens required
Raptors	On-foot nest searches—spring If extensive woodlands are present, aerial nest surveys prior to leaf-out	Ground and aerial nest surveys—spring	Ground and/or aerial nest surveys—spring	Ground and/or aerial nest surveys—spring	Aerial and/or ground nest surveys—spring
Waterbirds	For all wetlands: —breeding pair counts—May-June —brood counts—July —migration counts—April, October	For all surface water: —routine counts— 1 per month —no migratory or brood surveys	For all surface water: —seasonal counts including breeding pair and brood counts	Incidental observations	For all surface water: —breeding bird surveys—spring/summer —migratory surveys may also be required—fall, winter
Upland game birds	Pheasant crowing call counts—April, June Aerial and ground lek location surveys—spring Breeding bird lek counts—spring	Pheasant crowing call counts—spring Aerial and ground lek location surveys—spring Breeding bird lek counts—2 per spring Where leks will be disturbed, intensive telemetry studies are required to determine habitat needs Crop examination	Aerial and/or ground lek location surveys—spring Breeding bird lek counts—spring Vehicle or on-foot production surveys	Aerial and/or ground lek locations surveys—spring Breeding bird lek counts—spring	Breeding bird surveys—spring/summer

Table 5-9.—Accepted Data Collection Techniques[a]—Continued

Study category	North Dakota	Montana	Wyoming	Colorado	New Mexico
Songbirds and others	Variable width belt transects only in woodlands—spring Road survey—winter	Variable width belt transects in all habitats—spring	Variable width belt or point transects in all habitats and some habitat edge areas—spring	Variable width belt transect or variable circular plot in all habitats—spring	Variable width belt transect—spring/summer
Reptiles and amphibians	Incidental observations	Incidental observations	Incidental observations Trapping and call surveys in appropriate habitats—spring, early summer	Incidental observations	Systematic surveys—spring, fall
Aquatic vertebrates and invertebrates		Electro-shocking, seining, bottom sampling, dredging, etc. as appropriate (only for waters potentially affected by mining)	Stream quality classification Electro-shocking, seining, bottom sampling, dredging, etc. as appropriate	Stream habitat classification Electro-shocking, seining, bottom sampling, dredging, etc. as appropriate	Electro-shocking, seining, bottom sampling, dredging, etc. as appropriate—seasonally
Threatened and endangered species	No T&E critical habitats affected by mining Notification of observations required	Black-footed ferret; full FWS guideline search of prairie dog towns Bald eagle (Tongue R. only): aerial and ground surveys for roost or concentration areas—winter only	Black-footed ferret: density estimation and mapping prairie dog towns; full FWS guideline search of all towns Bald Eagle: aerial surveys for winter concentration areas	Black-footed ferret: full FWS guideline search of all prairie dog towns Bald eagle: aerial or ground surveys for roost sites or winter concentration areas	Black-footed ferret: full FWS guideline search of all prairie dog towns
All wildlife species	Incidental observations	Incidental observations	Incidental observations	Incidental observations	Incidental observations
Habitat	Habitat mapping at 1:4800 scale Distinct communities within a wetland must also be mapped	Delineation and mapping	Classification, delineation, and mapping	Delineation and mapping of all habitats and habitat features	Characterization, delineation and mapping of all habitats

[a] This table is not intended to represent a listing of methods or techniques required by the States for all operations. All study-area States derive baseline data requirements on a case-by-case basis. Some of the studies listed may not be required, depending on the ecological characteristics of the permit area and/or the availability of existing information.

SOURCE: Cedar Creek Associates, "Wildlife Technologies for Western Surface Coal Mining," contractor report to OTA, August 1985.

Mexico now emphasize habitat delineation and mapping rather than population inventories for reasons discussed below.

FWS and the State fish and game agencies both play important roles in requiring and designing wildlife data collection studies. The State agency is particularly important and usually is the principal regulatory consultant in operators' formulation of both baseline and monitoring data collection programs.

As in other disciplines, all States require site-specific studies; applicants may not substitute regional data and data from adjacent areas. Four of the States require studies to include buffer zones ranging from 0.25 to 2 miles around the proposed mine site. All States require 1 year (four seasons) of data collection and Montana prefers inclusion of two winter seasons. Montana also requires large operations not previously studied to have at least one full-time field biologist on-site for 1 year. None of the States routinely requires regional impact assessments, but only in cases of special concern. In Wyoming, a pronghorn study is being conducted by several mines in the Powder River basin. In Colorado, two different mines are conducting elk telemetry and sage grouse studies that extend outside the mine-site boundaries.

Important Sources of Previously Collected Data

Wildlife data collected outside the permitting process tend to be general or regional. They are therefore useful only as background information rather than as a substitute for baseline data. Data on species' life histories and requirements are available from literature published by government agencies and researchers. BLM has compiled wildlife baseline information in published reports for several Known Recoverable Coal Resource Areas (KRCRAs), and regional mapping of wildlife habitats and distributions is included on BLM's Unit Resource Analysis maps. Both the Colorado Department of Wildlife and the Wyoming Department of Fish and Game have computerized databases and mapping systems for the States' wildlife resources. FWS compiles site-specific data on raptors in areas where they may be affected by mining, and both regional and site-specific data on federally listed threatened and endangered species.

Data Collection by Operators

Collecting quantitative data on wildlife populations and impacts to those populations is particularly difficult for two reasons. First, as with vegetation, there is significant natural temporal and spatial variation in populations due to environmental factors unrelated to mining. Second, the mobility of wildlife makes species inventories, population estimates, and other measurements very difficult.

One result of these difficulties has been a shift of emphasis in quantitative wildlife data collection in recent years. Instead of collecting intensive data on population size and number of species present, regulatory authorities and operators are now concentrating their efforts on determining habitat characteristics and quality, the assumption being that if habitats are restored, wildlife will follow. This does not mean that population counts and species inventories have been abandoned. They are valuable for delineating the extent of habitats and are considered important indicators of habitat quality, but, because of the above-mentioned characteristics of wildlife, methodologies for measuring populations and number of species present are not considered sufficiently reliable to be the basis for wildlife reclamation.

Wildlife baseline studies usually collect the following types of data:

- species occurrence, including seasonal information;
- species distribution;
- relative species abundance or population estimates, including population size indices and species diversity values;
- reproductive success;
- food preferences;
- habitat preference;
- delineation of habitats; and
- habitat quality.

Table 5-10 shows the different techniques used to collect this information for different species.

Table 5-11 gives brief descriptions of the ways in which these different techniques are carried out.

Wildlife monitoring studies use the same data collection techniques as baseline studies, but tend to be much less intense, if they are conducted at all. They are not used to measure reclamation success directly, but indirectly as a gauge of the use of reclaimed acreage by wildlife (see ch. 7).

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Table 5-10.—Wildlife Baseline Data and Survey Techniques

Survey technique: data collected or derived

Big game:
Aerial surveys:
—Animal distribution, relative abundance, seasonal occurrence, population size estimates, reproductive success (fawn/doe or calf/cow ratios), concentration areas, habitat preference
Vehicle and on-foot surveys:
—Animal distribution, relative abundance, seasonal occurrence, reproductive success, habitat preference
Pellet group surveys:
—Habitat utilization, population size indices and trends
Browse evaluation:
—Habitat utilization, food preferences, habitat condition
Stomach contents or pellet analysis:
—Food preferences
Tagging/radio-tracking telemetry studies:
—Home range, animal movement, population size estimates, habitat utilization

Medium-sized mammals:
Aerial survey:
—Species occurrence, relative abundance
Scent station visitation survey:
—Species occurrence, population size indices and trends
Live trapping:
—Species occurrence
Night spotlight survey:
—Species occurrence, population density estimates
Strip transects:
—Population density estimates, habitat preference

Small mammals:
Live or snap-trap traplines or grids:
—Species occurrence, relative abundance, population size estimates, habitat preference, species diversity
Prairie dog town surveys:
—Burrow density, colony acreage

Raptors:
Aerial surveys:
—Species occurrence, nest locations, concentration areas
On-foot and vehicle surveys:
—Species occurrence, nest locations
Nest surveys:
—Species occupancy, nesting success and production

Waterfowl and other waterbirds:
Ground counts for wetlands and surface water:
—Species occurrence, animal distribution, relative abundance, seasonal occurrence, habitat preference
Breeding pair counts:
—Relative abundance of breeding birds
Nesting surveys:
—Nesting habitat
Brood surveys:
—Brood rearing habitat, nesting success, production
Wetland mapping and evaluation:
—Wetland habitat classification and locations

Upland gamebirds:
Aerial or ground surveys for leks (sage grouse or sharptailed grouse breeding grounds):
—Lek locations
Lek breeding bird counts:
—Lek attendance, indices of population size
Nesting surveys:
—Location and extent of nesting habitat
Brood surveys:
—Brood rearing habitat, production
Tagging/radio tracking studies:
—Animal movement, home range, habitat utilization
Crowing call counts (ring-necked pheasant):
—Indices of population size
Crop analysis:
—Food preferences, species occurrence
Roadside surveys:
—Indices of population size, habitat utilization

Songbirds and others:
Variable strip or circular plot surveys:
—Species occurrence, relative abundance, population size indices or estimates, habitat preference, species diversity
Roadside surveys:
—Species occurrence, relative abundance, population size indices, habitat preference, seasonal occurrence

Reptiles and amphibians:
Spring night call surveys:
—Species occurrence, relative abundance
Miscellaneous capture techniques:
—Species occurrence, relative abundance
Wetland searches and seining:
—Species occurrence, relative abundance

Fish:
Seining:
—Species occurrence, relative abundance, population size indices
Electroshocking:
—Species occurrence, relative abundance, population size indices
Aquatic habitat description:
—Habitat quality, classification

Aquatic invertebrates:
Artificial or natural substrate sampling, bottom sampling (Eckman dredge or surber sampler):
—Species occurrence, relative abundance, species diversity

Threatened and endangered species:
Aerial or ground winter concentration or roost surveys (bald eagle):
—Locations of roosts or winter concentration areas
Winter track or sign surveys (black-footed ferret):
—Species occurrence
Night spotlight surveys (black-footed ferret):
—Species occurrence
State sensitive species or species of "high Federal interest" (see applicable techniques by animal group listed above):
—Generally—species occurrence, habitat utilization, relative abundance

All species:
Incidental or opportunistic observations:
—Species occurrence, distribution, habitat utilization, relative abundance

SOURCE: Cedar Creek Associates, "Wildlife Technologies for Western Surface Coal Mining," contractor report to OTA, August 1985.

Table 5-11.—Table of Survey Techniques and Associated Methodologies

Survey technique: methodology

Terrestrial

Aerial survey:

—Slow fixed-wing aircraft or helicopter low level flights usually along standardized transects or conforming to specific habitats or topographic features. Record observations by species, numbers, and habitat.

Vehicle/on-foot surveys:

—Slow travel by vehicle or on foot along standardized survey routes. Record observations by species, number, and habitat.

Pellet group surveys:

—Record number of big game pellet groups intercepted by standardized transect or contained within standardized plots within different habitats.

Browse evaluation:

—Determine by standardized evaluation methods the degree of hedging of shrub and tree species by big game.

Stomach or crop contents or fecal material analysis:

—Laboratory analysis of contents to determine plant and animal material ingested.

Tagging/radio-tracking telemetry studies:

—Trap and distinctly tag or attach radio transmitter to a sample number of animals. Record tagged animals by location and habitat when observed during other surveys. Locate radio transmitter animals on a regular basis through use of two or more receivers and triangulation. Plot locations by habitat and individual located.

Scent station visitation survey:

—Establish standardized number of scent stations along standard (FWS) route. Stations consist of scent attractant in the middle of a circle of soft, smooth soil. Tracks of predator visitor recorded by species, station, and habitat.

Trapping:

—Set live "Sherman" or "Havahart" type traps or snap traps in random patterns, clusters, line transects, or grids in suitable habitats. Captures recorded by species, number, and habitat. Various statistical techniques or models used to estimate population size of small mammals.

Night spotlight survey:

—Slowly drive a predetermined route at night. With use of headlights and/or spotlight, record observations by species, number and habitat. Population indices calculated by dividing species numbers by acreage of corridor sampled by spotlight.

Strip transects:

—Slowly walk standardized transect in specific habitats and record species and numbers. Population indices calculated by dividing species numbers by acreage of corridor visually sampled.

Prairie dog town surveys:

—Estimated density of prairie dog burrows by various analytical techniques. Estimate acreage of town and plot extent and location of town on topographic maps.

Nest survey:

—Search all suitable habitat on foot with aid of binoculars or spotting scope. For inaccessible areas, search for nests by aerial survey.

Survey technique: methodology

Waterbird surveys:

—Make seasonal counts of all species and numbers occurring in all or a representative number of wetland or aquatic habitats. Record observations by survey area. For nest and brood surveys, search suitable habitat adjacent to wetlands or aquatic habitat and record nests and broods by location, species, and number.

Wetland mapping and evaluation:

—Classify all wetlands by standard FWS system. Map extent and location of all wetlands on topographic maps.

Lek breeding bird counts:

—Visit all known leks at least twice in early morning during spring breeding season. Record number of displaying males and females.

Crowing call counts:

—Count and record number of pheasant crow calls in early morning for a set time period at standardized stops along a standardized vehicle route.

Variable strip or circular plot surveys:

—Record species and numbers of birds by distance from observer along standardized transects or at predetermined points in all habitats. Population indices calculated for each species based on area sampled for that species.

Spring night call surveys:

—In appropriate habitats, record amphibian calls by species and number for a standard time period in the evening.

Black-footed ferret surveys:

—Use current FWS guidelines to search prairie dog towns for ferret track or sign. Use same guidelines for conducting night spotlight surveys.

Incidental observations:

—During all field activities, record all wildlife observations by species, number, location, and habitat.

Aquatic:

Seining and electro-shocking:

—Sample aquatic habitats using seine or electroshocking equipment. Record fish species captured by number and size.

Aquatic habitat description:

—Measure various standardized physical parameters and classify habitat using established classification systems.

Bottom sampling:

—Using standardized sampling equipment, take sample of bottom substrate. Using sieves and washing, separate out aquatic invertebrates. Classify by species and number.

Artificial or natural substrate sampling:

—Scrape or sample by other means representative samples from surface of natural bottom substrate. Separate out aquatic invertebrates and classify by species and number. For artificial substrate, secure standardized plates beneath water surface. Leave for standard time period and then scrape surface and separate out aquatic invertebrates. Classify by species and number.

SOURCE: Cedar Creek Associates, "Wildlife Technologies for Western Surface Coal Mining," contractor report to OTA, August 1985.

Chapter 6

Analytical Techniques

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Chapter 6

Analytical Techniques

CHAPTER OVERVIEW

Operators and regulatory authorities use a wide range of techniques to interpret and analyze data when predicting the impacts of mining and reclamation and designing reclamation, and the ultimate success of reclamation may depend on the validity of those techniques. **Some analytical techniques in use, however, may not consistently produce realistic predictions or valid interpretations with available data, or must rely heavily on assumptions to compensate for data inadequacies.**

Predicting the Impacts of Mining and Reclamation

A reasonable assessment of the impacts of mining and reclamation on *surface and groundwater hydrology*, over the life-of-mine area, can be made at most Western surface coal mines. Data will become more abundant and more reliable within each permit area due to monitoring as mine development progresses. In areas farther from the center of current operations, the knowledge of the physical system is less certain, and predictions of hydrologic impacts are less reliable. Regulatory authorities require worst-case analyses to compensate for this built-in error. So, as uncertainty about the system increases, assumptions made for input to the various analytical techniques become more conservative. Although this strategy avoids errors from underestimating potential impacts, it may entail other consequences from overstatements of impacts, including increased reclamation costs.

The development and use of quantitative methods for predicting impacts to groundwater quantity during mining—pit inflows and associated drawdowns—have tended to lag behind other quantitative developments in groundwater science. The effects of this are evident in the wide range of analytical techniques used in the mine permit applications reviewed for this assessment, which varied from simple linear extrapolations based on historical trends, to relatively simple analytical models, to sophisticated numerical computer models. A continuing problem in most mine permit applications is the lack of justification for selecting a particular analytical technique and description of the assumptions inherent in the analysis.

After mining, it is necessary to predict the nature and sources of spoils recharge, including postmining spoils aquifer characteristics; the time required for spoils resaturation and reestablishment of hydraulic equilibrium; and postmining spoils water quality. The nature and sources of recharge to the spoils are difficult to quantify without monitoring data. Most mines must use a water budget approach for calculating soil moisture storage and infiltration in order to estimate recharge from surface sources, and groundwater modeling techniques to predict postmining spoils aquifer flow characteristics.

Estimates of the time required for spoils resaturation and reestablishment of hydraulic equilibrium in the Western mining regions range from as few as 10 to as many as 2,900 years. While this introduces uncertainty about the long-term success of hydrologic restoration in some areas, that uncertainty was recognized during the formulation of the Surface Mining Control and Reclamation Act (SMCRA) and not considered so great that mining should be foreclosed in such areas. Continued analysis of field data on spoils recharge would reduce the level of uncertainty.

The validity of predictions of groundwater quality impacts—primarily levels of total dissolved solids (TDS)—**is critical because, given the time required for spoils to become fully saturated and groundwater flow patterns to be reestablished, there may be no way to verify the predictions by comparison with actual results. Analysis and prediction of postmining groundwater quality impacts are very difficult,** however, because the magnitude of such impacts is highly variable, the processes governing water quality changes are poorly understood, and the processes controlling recharge rates are unknown. **As a result, there is little agreement as to the best technique for producing consistent, valid predictions. Monitoring programs can be used to verify assumptions made about the trends of spoils-water quality over time, but will not necessarily provide information on the final postmining groundwater quality.**

Impacts on surface water quantity and quality are more readily observable than for groundwater, and the analytical techniques used to predict these impacts are more often based on actual conditions than on assumptions. The greatest potential impact to surface water quality from mining and reclamation is an increase in total suspended solids (TSS). When site-specific data are not available (the usual case for ephemeral streams), a well-accepted method is available to estimate the amount of sediment that will erode from the mine site and be subject to transport downstream during a precipitation event. Surface water quantity impacts are estimated primarily to support surface water engineering design, and valid statistical techniques are available for computing runoff volumes and peak flows. Deterministic models also are available, but their results are only as valid as the assumptions used about the hydrologic regime of the site.

The uncertainties in cumulative hydrologic impacts assessments (CHIAs) are greater than in determinations of the probable hydrologic consequences (PHC) of mining because of the absence of data from areas in which there is no active mining, and because of the lack of coordination and standardization in data collection (see ch. 5). **The uncertainty could be minimized if regulatory authorities used monitoring and repermitting data to recalibrate the models used in CHIAs and to assess the validity and sensitivity of the various input assumptions.** Periodic sensitivity analyses of the variables would provide valuable information about data inadequacies and could be used to focus data collection.

***Wildlife* are mobile, unpredictable, and adaptable, all of which make their responses to environmental change difficult to predict.** It also is extremely difficult to identify and isolate those unpredictable responses or adaptations that are attributable to mining and reclamation from those caused by any of the other environmental factors present. **As a result, quantitative techniques for predicting the impacts of surface coal mining and reclamation activities on wildlife populations have not been found to be effective and are attempted infrequently.** Instead, these assessments generally are made by intuitive professional judgment based on a knowledge of the operational aspects of the mine and of the ecological resources of the mine site and surrounding area.

Statistical analyses of the effectiveness of wildlife mitigation measures are possible but very costly. Where such analyses have been undertaken, their results generally are consistent with these intuitive professional judgments, indicating that a subjective approach to wildlife impact assessment based on measures of habitat quality from key ecological parameters, probably is the most satisfactory method of predicting impacts on wildlife resources.

***Revegetation* analyses focus on predicting the success of revegetation. While OTA found little emphasis on the development or use of analytical techniques for predicting long-term revegetation success, the lack of quantitative models does not appear to diminish the potential for accurate predictions.** The most common, and probably most valid technique for predicting revegetation success is to consider results of the most recent technology at other mining operations in the region with similar soil, overburden, and climatic characteristics.

However, there are few vehicles for disseminating the results of different revegetation techniques. Indeed, some companies may be reluctant to share such information for competitive reasons. Moreover, some techniques may show initial promise, but poor long-term results, or vice versa. With a qualitative comparative analysis for revegetation planning, the former may be adopted, and the latter rejected, prematurely.

Analytical Techniques Used in the Design of Reclamation

Accurate characterization of the overburden and delineation of potentially deleterious overburden material, design of an optimum soil-salvage plan, design of well-stabilized stream channels, and design of efficient sedimentation control measures are important factors in the ultimate success of reclamation.

***Overburden* forms the basic material for the reclamation process, and the chemical and physical character of the overburden are key factors in determining impacts on postmining spoils hydraulics and water quality, as well as revegetation success.** However, overburden is not easily observed premining, the geology of the overburden in many of the mining regions of the West is highly variable, and the science of overburden characterization is neither old nor well-established. As a result, **analysis of the physical and chemical properties of overburden is difficult.** Thousands of overburden data points will be generated at the average Western surface mine and there are no well-established procedures for interpreting these data to determine the chemical suitability of overburden materials. Operators and regulatory authorities generally agree on the methods for characterizing overburden and for handling potentially deleterious materials on a case-by-case basis. The primary risk of not identifying such materials before backfilling is that problems may not become evident until after bond release, yet may require costly reconstruction.

The *redressed soil* serves as a chemical and physical buffer between the disturbed mine spoils and surface water, vegetation, and wildlife resources, and also is a critical element for successful reclamation. Soils are relatively easy to observe and the science of soil characterization is well established. A low sampling density can result in significant errors in estimating the volume of salvageable soil material, however.

Valid approaches to design of an erosionally stable *surface drainage system* are available, ranging from direct field measurement of channel cross-sections and profiles that duplicate the undisturbed channel, to computer-assisted, detailed hydraulic analyses. **In the case study mines reviewed for this assessment, however, the amount of detail in such designs ranged from virtually none to very elaborate geomorphic and hydraulic studies, although an encouraging trend toward a comprehensive, multidisciplinary approach to design of surface drainage systems was observed.** Greater attention to drainage system design in permitting could reduce the potential for costly repairs of erosion damage during reclamation.

Techniques for the design of *hydrologic and sediment control facilities* have changed very little since SMCRA, although there has been an increasing use of computers, and a gradual standardization of runoff- and sediment-estimating techniques. The techniques in use accommodate the lack of site-specific data for sediment erosion and transport rates by providing relative estimates for comparison of alternative designs. Use of a computer allows rapid, accurate analysis so that larger areas can be simulated in greater detail and over shorter time steps than with hand calculations. **Monitoring data could be used to calibrate the models used, but OTA found little indication that this is occurring.**

Restoration of *alluvial valley floors* (AVFs) combines some of the more rigorous design aspects of surface and groundwater restoration. SMCRA only allows mining in AVF areas that are not significant to agriculture. There is little experience with mining in these areas under the SMCRA design and performance standards, although several plans for AVF restoration have been approved by the regulatory authorities. Premining analysis of the essential hydrologic functions of AVFs and postmining evaluation of AVF reclamation are based on accepted engineering and hydrogeologic principles, and operators and regulatory authorities view the probable success of reclaiming AVFs with confidence. As with hydrologic restoration in non-AVF areas, however, if AVF areas are mined it may be decades or centuries after mining and reclamation before the success of their hydrologic reclamation can be assessed completely.

USES OF AND REQUIREMENTS FOR ANALYTICAL TECHNIQUES

The term "analytical techniques," as used in this report, refers to all methods used to interpret and analyze baseline and monitoring data in order to make them useful in reclamation planning, permitting, and evaluation. **The use of analytical techniques for data interpretation is an integral part of the process of planning and evaluating reclamation, and the applicability and accuracy of the techniques used will, to some extent, determine the validity of that planning and evaluation, and therefore the ultimate success of reclamation.** The analytical techniques used in the permit applications reviewed for this assessment ranged from qualitative techniques in which the conclusions are dependent on professional judgment, to objective, quantitative modeling that requires sophisticated computer software to analyze the data plus technical competence to interpret the computer analysis. Some analytical techniques in use, however, may not consistently produce realistic predictions or valid interpretations with available data.

In this chapter, analytical techniques are divided into two broad groups: those used to predict the impacts of mining, and those used to plan and design reclamation. Techniques used to evaluate the success of reclamation are discussed in chapter 7. To the extent possible, individual analytical techniques are described and their applications, merits, and limitations discussed. Examples of their use, taken from case studies of Western mines (see vol. 2), are illustrated in boxes.

SMCRA's requirement for a detailed reclamation plan that demonstrates an operation's ability to meet the performance standards implicitly requires the development and use of analytical techniques for designing and reviewing reclamation practices.[1] SMCRA includes few explicit requirements for the development and use of such techniques,[2] however, beyond the PHC determination and the CHIA (see ch. 4).

There are, however, informal requirements in the State regulatory programs. For example, the Wyoming Department of Environmental Quality (DEQ) expects data in permit applications to be interpreted to some degree and would likely reject an application that included raw data or conclusions not supported by data analysis. At a recently permitted mine in Wyoming, the techniques used to analyze premining data and to estimate impacts to the surface and groundwater systems were chosen to meet guidelines prepared by DEQ.[3] On the other hand, at least one permit application in New Mexico contained raw, uninterpreted data.[4]

ANALYTICAL TECHNIQES USED TO PREDICT THE IMPACTS OF MINING

Introduction

Predictions of the impacts of mining on the various components of the ecosystem support the demonstration, in the permit application package, that the performance standards will be met, and enable the regulatory authority to make the finding of reclaimability required by SMCRA before a permit can be issued. The resulting reclamation practices in turn affect both the profitability of the mining operation and the ultimate success of the reclamation. It is therefore in the best interests of all parties that the most reliable and efficient methods be used to predict the impacts of mining.

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[1] The distinction is made between laboratory techniques used to derive data from samples of soil, water, vegetation, etc., and analytical techniques used to interpret those data. The former often are required explicitly in State regulations or guidelines and are required to be performed in a prescribed manner (see ch. 5).

[2] The recent challenges to the Federal regulations implementing SMCRA (see ch. 4, box 4-C) will affect the applicability of various analytical techniques for predicting both the impacts of mining and the success of reclamation, including the techniques used for PHC determinations and CHIAs, as well as those used to predict mine-induced changes in streamflow sediment load and to design sediment controls.

[3] See case study mine N in reference 30.

[4] See case study mine L in reference 27.

The ease and accuracy of predictions of the environmental impacts of mining varies widely among disciplines. For example, extracting coal by surface mining methods obviously will destroy the premine vegetation resource temporarily. It is less obvious whether overburden strata will have detrimental effects on the postmining vegetation. The less obvious the impact of mining on the environment, the greater the need for careful interpretation and analysis of sufficient data to predict the potential extent of adverse impacts in order to design reclamation properly.

Impacts to the quality and quantity of the surface and groundwater resources, and to the quality and quantity of the soil resource and the material within the postmining root zone are two major areas of concern because because they are critical to the postmining ecology, yet they embody a high degree of uncertainty. Impacts to vegetation, and to a limited extent wildlife, are determined indirectly from the predicted characterization of the postmining soil and water resource.

Although in this chapter the discussions of analytical techniques are categorized by discipline (i.e., groundwater hydraulics, overburden chemistry), it is important to keep in mind the concept that reclamation planning involves predicting the impacts of mining on a complex, integrated ecological system. Overburden stratigraphy and geochemistry determine groundwater hydraulics and water quality; soil volume and quality contribute to vegetative productivity. None of the components of the system is independent or isolated. As reclamation planning becomes more interdisciplinary, so do the more advanced analytical techniques, which are beginning to utilize the full range of modern computing technologies to simulate reclamation problems.

Predicting Groundwater Impacts[5]

Surface coal mining can affect groundwater resources in two ways. During mining, the pit acts like a large well, creating a low-pressure zone ("cone of depression") that draws water from the surrounding aquifers. This can cause local springs to fail, or wells located close to the disturbed area to be dewatered to the extent that they are no longer usable (fig. 6-1A,B). After mining, the shallow aquifers in the mine area are replaced with spoils materials that may have hydrologic characteristics substantially different from premining conditions (fig. 6-1C).

Impacts to groundwater quality during mining are minimal. Because the groundwater flow is in the direction of the pit, there is little opportunity for any contaminants introduced by mining to affect offsite areas. **The greatest potential for groundwater quality impacts arises after mining, when groundwater saturates the spoils and returns to a steady-state flow pattern.** This section describes the analytical techniques used by mine operators and regulatory authorities to predict the magnitude of the impacts to the groundwater system during mining (which, it must be remembered, can last 40 or more years), and the methodologies used to predict or design postmining aquifer characteristics.

These impacts, as well as those to surface water quantity and quality, are predicted in the PHC determination. The geographic extent of this impact analysis is not defined in SMCRA, and the size of the area covered by a PHC determination varies from permit to permit. In areas of concentrated mining activity, the PHC determination may encompass one or more adjacent mines. At a mine in Montana, for example, the Department of State Lands required the PHC to include hydrologic impacts associated with another company's proposed surface coal mine operation immediately adjacent to the applicant's mine area.[6]

The PHC determination must assess the potential for: 1) groundwater contamination; 2) contamination, diminution, or disruption of surface or groundwater supplies already in use; and 3) impacts to the surface water hydrologic balance. Some permit applications reviewed for this assessment used the 5-year term-of-permit area and others the life-of-mine area, depending on the regulatory authorities' needs for CHIAs (see ch. 4, box 4-C).

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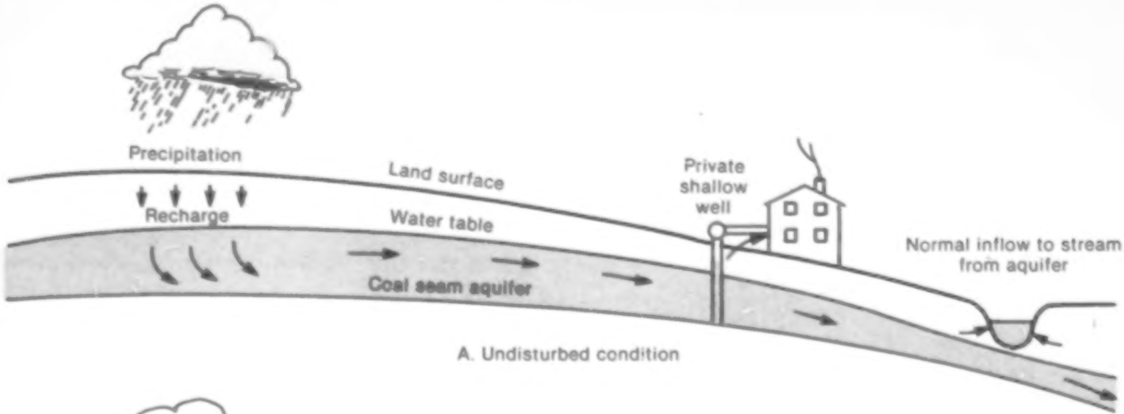
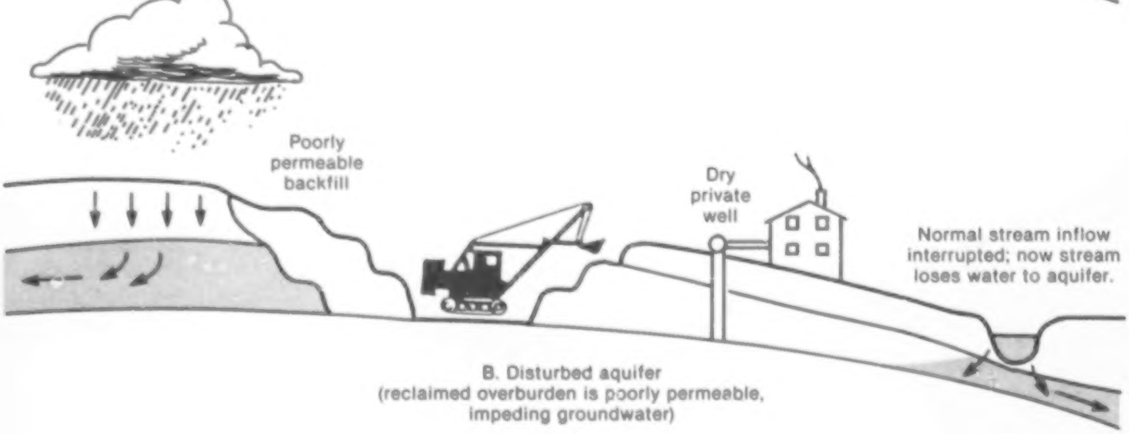
[5] Unless otherwise noted, material in this section is adapted from reference 30.

[6] See case study mine E in reference 30.

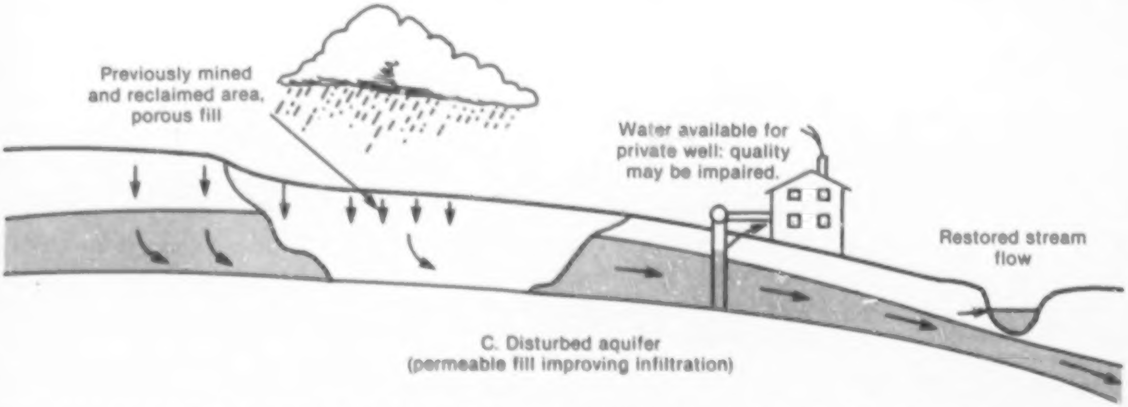
Figure 6-1.—Possible Impacts of Mining Aquifers


Precipitation
Land surface
Recharge
Water table
Coal seam aquifer
Private
shallow
well
Normal inflow to stream
from aquifer

A. Undisturbed condition


Poorly
permeable
backfill
Dry
private
well
Normal stream inflow
interrupted; now stream
loses water to aquifer.

B. Disturbed aquifer
(reclaimed overburden is poorly permeable,
impeding groundwater)


Previously mined
and reclaimed area,
porous fill
Water available for
private well: quality
may be impaired.
Restored stream
flow

C. Disturbed aquifer
(permeable fill improving infiltration)

SOURCE: F.E. Roybal, et al., Hydrology of Area 60, Northern Great Plains and Rocky Mountain Coal Provinces, New Mexico, Colorado, Utah and Arizona; USGS Water-Resources Investigations, OFR 83-203, p. 7.

Groundwater Impacts During Mining

To predict the impacts on groundwater resources during mining, it is important to define the aquifers in a mine area, determine the premine level of the water table, and determine to what extent the proposed pit will intersect the water table and disrupt the aquifer(s). The areal extent of impacts on groundwater levels depends largely on the geologic and hydrologic setting of the mine and the duration of mine dewatering. Aquifer boundaries generally coincide with geologic-unit boundaries, and the geology of the overburden and coal must be characterized in order to assess the potential impacts of mining. Once drawdowns and affected areas are defined, their impact must be determined by examining existing groundwater uses within the cones of depression.

In the coal regions of North Dakota, Montana and eastern Wyoming, for example, the sandstone, siltstone, and shale strata are complex and can change abruptly. The numerous aquifers in these strata tend to be small and to have limited communication with each other. As a result, water-level changes resulting from mining usually are relatively localized in the overburden. In these areas, however, the coal itself is a regional aquifer.

In the coal mining regions of northwestern Colorado, and western and southern Wyoming, geologic units are more continuous, aquifers may or may not be confined, and the potential for mining to cause changes in water levels over a large area is greater. In New Mexico, for the most part, the water levels are quite deep and below the level of mining except for very local perched water tables.

Prediction of pit inflows and associated drawdowns requires determination of the hydraulic properties of affected aquifers and knowledge of the mining methods and the mining schedule. Aquifer hydraulic characteristics that must be described include transmissivity, saturated thickness, storage coefficients, locations of hydrologic barriers or boundaries, and areal extent of aquifers. Long-duration pump tests are conducted to define aquifer hydraulic parameters. The pump tests must be analyzed with full consideration of boundary conditions determined from geologic maps and cross-sections in order to provide valid results. Selection of the technique for such analysis depends on many factors, including site-specific hydrogeologic conditions, pit configuration, and the experience and capability of the investigator. The available techniques are summarized in table 6-1 and described below; additional details may be found in the technical report on hydrology in volume 2.

For existing mines, where substantial amounts of data are available, pit inflows and drawdowns often are predicted from historical data on adjacent and hydrogeologically similar areas. This method is illustrated in boxes 6-A and 6-B for mines in North Dakota and Montana, which both used simple linear extensions of historical trends but with different amounts of data and demonstrations of premining conditions. In cases like the North Dakota example, where sufficient data on inflows and drawdowns are available and they demonstrate that the impacts of mining are minimal, the estimates should be valid provided that no changes are made in mining rates or methods and no unforeseen boundary effects are encountered. Thus, there would be no reason to conduct a more sophisticated analysis than the one used in that example.

When historical data are not available for estimating the impacts of mining, mathematical modeling must be used. The first step in developing a mathematical model is to translate the physics of the hydrologic process into mathematical terms. This requires an understanding of the process of groundwater flow and its relationship to the various hydraulic parameters. Certain simplifying assumptions about the hydrologic system, as well as assumptions about initial and boundary conditions, have to be made. Partial differential equations can then be derived that describe the physical process and form the basis of the mathematical model (13).

The mathematical model can be solved in one of two ways, thus dividing the models into two groups: **analytical models** use some additional assumptions for the groundwater flow equation, such as radial flow and infinite aquifer extent, and can be solved by hand calculation or using pro-

Table 6-1.—Summary of Analytical Methods Typically Used for Computation of Pit-Water Inflows and Resultant Drawdowns

Method	Data requirements	Advantages	Disadvantages
Extrapolation of existing data.	Historic records of pit inflows and resulting drawdowns.	Easiest method to use. Proven for given site conditions.	Not applicable for new mine. Not applicable to changing aquifer conditions or mining methods or schedules.
Simple application of Darcy's Law.	Potentiometric surface gradient, aquifer transmissivity.	Simple to use.	Limited predictive tool because either gradient or flow must be assumed. Basic assumptions of aquifer homogeneity and parallelism between base of aquifer and water table seldom met. Hydrologic barriers and boundaries difficult to address.
Theis nonequilibrium radial-flow equations.	Potentiometric heads, aquifer transmissivity and storage coefficient.	Simple to use. Better simulation in most cases than simple Darcy. Can simulate barriers and boundaries with image wells.	Limited predictive tool because drawdown or pit inflow must be assumed. Basic assumptions of aquifer homogeneity, instantaneous release of water with change in head, and infinite aquifer extent seldom met. Radial flow may not occur. Difficult to simulate movement of pit and reduction of aquifer transmissivity in time.
One-dimensional flow equation for fully penetrating excavation.	Potentiometric heads, aquifer transmissivity, location(s) of aquifer recharge sources.	Simple to use. Good simulation in certain cases.	Assumption that source of recharge and mine pit are infinite in length and parallel not met. Assumption that recharge equals pit inflow not always met. Requires assumption of drawdown or flow.
Combined radial and linear storage-release equations.	Potentiometric heads, aquifer transmissivity and storage coefficient.	Simple to use. Better simulation of actual pit configuration than previous methods.	Same basic assumptions as Theis equation. Does not consider downgradient flow of water—only storage release.
Finite-difference digital computer model (FDM).	Potentiometric heads, boundary conditions, aquifer transmissivity and storage coefficient, recharge; all must be input for respective nodes.	More accurate than previous methods. Better simulation of moving pit than previous methods. Facilitates accommodation of changes once data input is complete. Capable of handling larger problems, such as cumulative impacts of several mines, than previous methods.	More difficult to use than previous methods. Requires access to computer. Requires substantial calibration and verification. Difficult to check results without independent model study. Need to estimate recharge.
Finite-element digital computer model (FEM).	Same as FDM.	More flexible data input than FDM. More precise results than FDM. Handles irregularly shaped areas and complex boundary conditions better than FDM.	More difficult to use than FDM. Requires substantial calibration and verification. Difficult to check results without independent model study.

SOURCE: Western Water Consultants, "Hydrologic Evaluation and Reclamation Technologies for Western Surface Coal Mining," contractor report to OTA, August 1985.

Box 6-A.—The Use of Historical Data Extrapolation Based on Limited Available Data[1]

A moderate-size lignite mine in North Dakota has been mining since 1946, although hydrologic monitoring data—and thus impacts to the groundwater system—have only been recorded since 1977. Hydraulic conductivity for the aquifers in the mine area were determined by short-term, low-yield pumping tests. Based on water-level measurements from monitoring wells in and around the permit area, the applicant developed potentiometric surface maps for the two aquifers likely to be affected by mining—the lignite bed and the underburden sandstone. These maps reflect the dewatering influence of the existing mine pit on water levels in the two aquifers. This relationship is especially noticeable in the lignite bed, where hydraulic gradients steepen dramatically adjacent to existing mine pits. Most of the domestic and stock water-supply wells in the vicinity of the mine are completed in aquifers deeper than the lignite or sandstone aquifers. Data from these wells were of little use in determining hydrologic impacts of mining activities except to demonstrate that the deeper aquifers were unaffected. Historical data were used in the permit application to demonstrate that fluctuations in the potentiometric surface have been very limited in wells in excess of one-half mile from active mining areas. Limited drawdown, and low hydraulic conductivities were used by the operator to demonstrate that no additional hydrologic analysis was necessary and to justify the request to reduce monitoring frequency.

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[1] See case study mine B in reference 30.

Box 6-B.—Data Extrapolation With Extensive Historical Data[1]

A moderate-sized mine in the Powder River basin of Montana demonstrates more extensive use of historical data. The primary sources of hydrologic data were data previously compiled by the applicant for an earlier mine permit, plus a very large database (see ch. 5, box 5-H) compiled by the Montana Bureau of Mines and Geology as part of a regional hydrologic assessment encompassing both the case study mine and one 1.5 miles away. The approach was to develop comprehensive databases of current and historical information by which groundwater conditions within, and in the immediate vicinity of, the two mine areas could be compared to historical and current conditions in areas distant from the mines. A large amount of information was compiled regarding the stratigraphic positions of aquifers, and the uses and quality of groundwater over a broad geographic area. Much of this information was derived from the records of water wells and developed springs, augmented for the purposes of the hydrologic studies by selective water sampling. Some of the database goes back 60 years and provides a good perspective on hydrologic conditions prior to mining. Regional hydrologic data were analyzed statistically to determine arithmetic means and ranges of major chemical constituents in groundwaters, yields and water elevations of specific aquifers, and the temporal and spatial distribution of groundwater mineralization within specific aquifers. This analysis included mapping of regional directions of groundwater movement and sources of recharge and discharge within the uppermost coal seam, and the quality of water at springs, wells, ponds, and streams. The groundwater database derived from the monitoring, testing, and sampling of observation wells within and near mine areas was analyzed, and the results were compared to the regional analysis described above to determine the effects of mining on groundwater supplies and to provide predictions for future groundwater conditions. Some 70 hydrographs were used to identify the relative amount and areal extent of aquifer impacts from mine dewatering, to estimate natural recharge rates to aquifers, and to illustrate recovery of groundwater levels in spoils.

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[1] See case study mine F in reference 30.

grammable calculators or personal computers; and **numerical models,** in which the partial differential equations are approximated numerically by computer, and the continuous variables are replaced with discrete variables that are defined at points (grid nodes) in the area being modeled to generate a system of algebraic equations that are solved by matrix mathematics.

Analytical Models.—The available analytical models include the Darcy Equation, Theis Non-Equilibrium Equations, and various one-dimensional flow equations (see table 6-1).[7] All these methods use data readily available from standard aquifer tests, geologic investigations, and mine-plan maps and figures. **Any of these analytical flow models can be used to provide reasonably accurate predictions of pit inflows and drawdowns, provided that the investigator performing the calculations does so in full recognition of the assumptions on which the equations are based, the applicability of the individual methods to the site-specific hydrogeologic conditions, and the mining methods and schedules (see box 6-C).** The most common mistake made in this type of analysis is the use of an equation that is familiar or convenient but is not valid for the conditions that have been or that will be encountered. For example, two of the assumptions on which the Darcy Equation is based are invalid for most surface mining situations, and this equation can provide unreliable estimates of pit inflow if not used properly.

In addition, these analytical flow modeling techniques cannot account for the wide variations in aquifer hydraulic characteristics and boundary conditions normally encountered at mine sites. The simpler analytical techniques are, however, widely known to both industry and regulatory personnel, do not involve the use of proprietary analytical methods, and can be duplicated easily, all of which facilitate regulatory review and permit approval.

Box 6-C.—Use of the Theis Non-equilibrium Equation[1]

At one post-SMCRA mine in the Powder River basin of Wyoming, the operator estimated life-of-mine groundwater drawdown using predicted inflows to the mine pits and a computer program that solves the Theis equation to model the aquifers in the mine area. Pit inflows were modeled by simulating wells pumping at a constant rate at each of the pit locations, and drawdowns from the simulated wells at each pit location were summed using the Theis equation. A well with an injection rate equal to the pumping rate simulated the effects of ceasing pit dewatering. The problem was simplified by assuming that the mine pit would function as a large, circular well. This assumption fits the theoretical basis of the method used, and presumably is valid, although there is no discussion in the permit application as to how well the underlying assumptions of aquifer homogeneity, isotropy, infinite areal extent, infinitesimal well diameter, and constant coefficient of storage were met. Drawdowns calculated using this method may be conservatively high because the method does not take into account effects of the change from confined to unconfined storage in the aquifers as drawdowns bring the water surface below the top of the coal aquifer. Moreover, this method is not very reliable unless it is carefully calibrated to local conditions. Also, simulation of the effects of ceasing pit dewatering by synthetic injection wells is not reliable unless the locations and injection rates of the wells are chosen carefully. The permit application does not contain any information on calibration or on how the locations and injection rates of wells were chosen. It is likely that this methodology is acceptable to the regulatory authority, however, because a worst-case is simulated and the predictions will be conservative.

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[1] See case study mine F in reference 30.

In employing any of these analytical flow modeling techniques to predict pit inflows or drawdowns over the life of a mine, the number of calculations required can become large. Many investigators solve the equations using programmable calculators or personal computers, which improve both computational accuracy and speed, and a large amount of software has been developed to facilitate the analysis. Due to the enormous number of calculations required to calculate inflow and drawdown for each configuration of a moving pit (theoretically, there are infinite configurations), the investigator generally will select a limited number of pit configurations and perform a few "worst-case" predictions. Although this usually results in the overstatement of predicted drawdowns, worst-case studies are required by regulatory authorities to compensate for the built-in errors in the analysis methods.

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[7] Detailed descriptions of these analytical flow models may be found in reference 30 in vol. 2 of this report.

A common means of overcoming the limitations of analytical flow models is to use a combination of mathematical prediction and direct observation via monitoring wells. This was the approach at one mine in Montana, which has been in operation since 1972.[8] The Darcy equation was used in conjunction with a flow net to estimate pit inflows and interactions between aquifers, and groundwater system monitoring was used to show development of the cone of depression. This combination of methodologies generally is not practicable at a new mine where sufficient monitoring data have not been amassed.

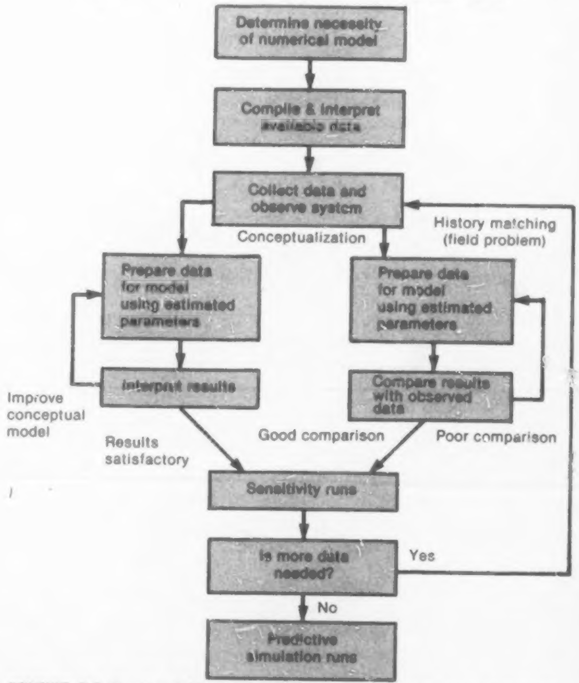
Numerical Flow Models.—Numerical flow models are used for systems that are more complex in terms of spatial variability or boundary conditions; because of the extensive computations required, they are only practical when solved by computer (13). These models can be used to predict the response of groundwater systems to mining as a function of aquifer parameters (transmissivity and storage coefficient), hydrologic and geologic boundary conditions, and the positioning of the pit within the system being modeled. The goal is to predict the value of an unknown variable (e.g., potentiometric head or discharge rate) at one or more specific locations, by solving a system of algebraic equations for each discrete time-step or region within the system.

Numerical flow models are gaining in use among large operators, even though they are time-consuming to set up initially and can be more difficult for the regulatory authority to review even with proper documentation. The primary value of numerical models is as a qualitative guide to the behavior of an aquifer under various simulated stresses; more often, however, they are used as predictive tools.

Numerical models are more flexible than analytical models. Thus they can better represent the physical and temporal variations in a system. Moreover, the same model can be used to analyze a variety of problems. Numerical models also are not limited by some of the restrictive assumptions necessary for analytical models, and they can perform more sophisticated sensitivity analyses. These models, and the concepts on which they are based, are well accepted by hydrologists. However, the accuracy of the predictive results of numerical computer models is variable and depends on model limitations, accuracy of calibration, reliability of input data, and individual aquifer characteristics (9).

The application of a numerical groundwater model involves four primary activities: 1) data collection, 2) data preparation for input to the model, 3) trial-and-error calibration, and 4) simulation (see fig. 6-2) (6). Numerical models can be run with any amount of available data, but the quantity and quality of input data will determine

Figure 6-2.—Flow Diagram of Model Use


Determine necessity of numerical model
Compile & interpret available data
Collect data and observe system
Conceptualization
History matching (field problem)
Prepare data for model using estimated parameters
Prepare data for model using estimated parameters
Interpret results
Compare results with observed data
Improve conceptual model
Results satisfactory
Good comparison
Poor comparison
Sensitivity runs
Is more data needed?
Yes
No
Predictive simulation runs

SOURCE: C.R. Faust and J.W. Mercer, "Ground-water Modeling: An Overview," *Ground Water*, vol. 18, No. 2, 1980, pp. 108-115.

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[8] See case study mine D in reference 30.

the validity of the results ("garbage in, garbage out"). Special attention must be given to the collection, preparation, calibration, and verification of data input to the model. As shown in table 6-2, the two numerical models currently in use require extensive input data and substantial calibration and verification, and their results are difficult to check.

Numerical models also require an understanding of the behavior of the hydrologic system. Flow of groundwater and declines in water level can be described and analyzed mathematically, provided adequate hydrologic and geologic information is available (see table 6-2) (13). Thus, the model is not simply a predictive tool, but also an aid in conceptualizing aquifer behavior.

A numerical model is useful only if it is documented (i.e., there is a model description, a listing of its code, and a user's manual), is available at no cost in the public domain (this includes models developed by Federal and State agencies, or by universities under Federal grants), and has been applied once or more in the field. Out of 138 flow models examined in one survey, 39 were fully documented, 57 were available to the public, and 106 had been applied in the field; only 20 met all three criteria and were considered useful (1).

There are two mathematical flow modeling techniques in general use: finite-difference models (FDMs), and finite-element models (FEMs). The important components and steps of model development for the two alternative methods and their application are shown in figures 6-3 and 6-4; detailed descriptions may be found in volume 2. Although selection of the modeling technique should be made to correspond with the physical system being modeled (a tenet which holds for all analytical techniques), it is more commonly made to fit the user's experience or computer system (8).

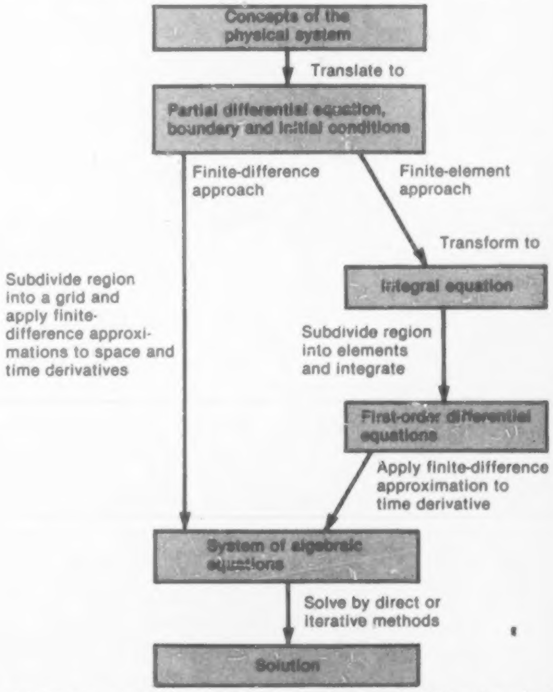
Table 6-2.—Possible Data Requirements for Groundwater Flow and Solute Transport Models

Requirements for groundwater flow models:
- hydrologic information on areal extent, boundaries, and boundary conditions of all aquifers;
- locations of major surface-water bodies;
- water table, bedrock elevation, and saturated thickness information;
- confining layer information;
- transmissivity information for the study area, derived from pump tests or maps;
- permeability information on the relations of saturated thickness to transmissivity;
- the extent of aquifer and stream hydraulic connection;
- type and extent of recharge areas;
- groundwater pumping information;
- streamflow information; and
- precipitation information.

Requirements for solute transport models (in addition to above data):
- estimates of hydrodynamic dispersion;
- effective porosity information;
- natural water quality information for the aquifer;
- hydraulic head distribution in the aquifer;
- water quality distribution in the aquifer;
- stream water quality;
- understanding of chemical reactions going on in the groundwater system; and
- sources and concentrations of pollutant.

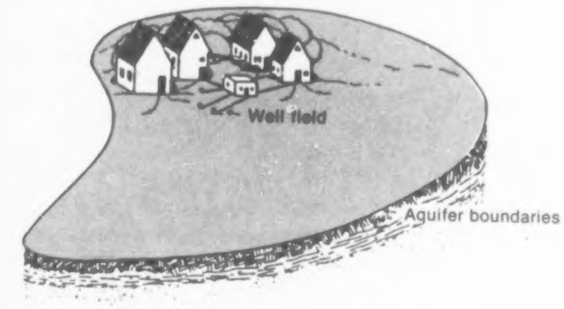
SOURCE: K. Kirk and G. McIntosh, *Ground Water Modeling by Use of OSM Modified Prickett Lonnquist Ground Water Model*, U.S. Department of the Interior, Office of Surface Mining, training seminar, 1984.

Figure 6-3.—Generalized Model Development by Finite-Difference and Finite-Element Methods

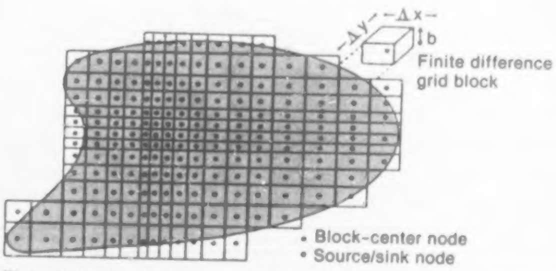

Concepts of the physical system
Translate to
Partial differential equation, boundary and initial conditions
Finite-difference approach
Finite-element approach
Transform to
Subdivide region into a grid and apply finite-difference approximations to space and time derivatives
Integral equation
Subdivide region into elements and integrate
First-order differential equations
Apply finite-difference approximation to time derivative
System of algebraic equations
Solve by direct or iterative methods
Solution

SOURCE: C.R. Faust and J.W. Mercer, "Ground-water Modeling: Numerical Models," *Ground Water*, vol. 18, No. 4, 1980, pp. 395-409.

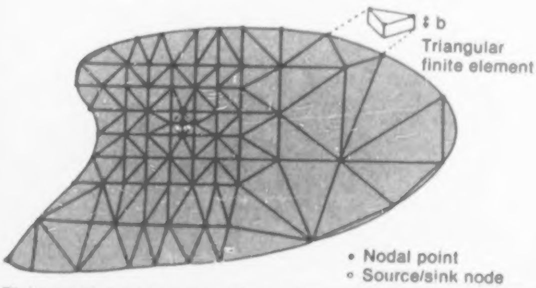
Figure 6-4.—Application of Mathematical Flow Modeling Techniques



Map view of aquifer showing well field and boundaries.



Finite-difference grid for aquifer study, where Δx, is the spacing in the x-direction, Δy is the spacing in the y-direction and b is the aquifer thickness.



Finite-element configuration for aquifer study where b is the aquifer thickness.

SOURCE: C.R. Faust and J.W. Mercer, "Ground-water Modeling: Mathematical Models," *Ground Water*, vol. 18, No. 2, 1980, pp. 212-227.

At present, two finite-difference models are used frequently in Western surface coal mining. The Prickett-Lonnquist model, developed by the Illinois State Water Survey (box 6-D), has been used by mine operators and the Office of Surface Mining (OSM) to determine both site-specific and cumulative groundwater drawdown impacts for permit applications and CHIAs (see below) (13,19). The model is available in the public domain for mainframe computers and can be purchased for a modest sum for use on mini- and microcomputers. The U.S. Geological Survey (USGS) uses another model developed by Trescott and others in 1976 (box 6-E).

Although the FDM currently is more widely used, there is a consensus among computer modelers that the newer FEM is a superior analytical technique and eventually will be the predominant type of model used for the analysis of groundwater flow (30). Overall, the FEM is more flexible than the FDM because it has a more advanced mathematical basis and can provide higher levels of accuracy, but data input and programming are more difficult. Using the FDM, data input and customized changes to the program are accomplished more easily, but the relatively low accuracy of predictive results is unacceptable for some applications. However, when the typical low precision and sparse quantity of available data for large areas are considered, the distinction between the accuracy of the two methods is probably insignificant.

Digital computer models are not an appropriate analytical technique in every instance. For example, the USGS was unable to produce a verifiable, calibrated groundwater flow model of the Powder River basin coal mining region, covering some 4,500 square miles and 21 mines in northeastern Wyoming. This model was requested, and partially funded, by the Wyoming regulatory authority as part of their obligation to perform a CHIA for this area. Due to time and budget constraints, USGS simplified the groundwater system, assuming it consisted of only three separate, unrelated aquifers: overburden, coal, and underburden. Because of the considerable discharge or recharge from the vast bodies of burned-out coal ("scoria") in the area, and the significant interaction between aquifers, the simplifying assumption of separate and unrelated aquifers produced unreliable results. While part of the reason for lack of success may have been the inadequate time and money, the unsuccessful study caused USGS to question whether such a large area could be modeled (28).

Box 6-D.—Use of the Prickett-Lonnquist Model To Simulate Cumulative Drawdowns[1]

A Powder River basin operator used the Prickett-Lonnquist model to simulate site-specific and cumulative drawdown at the mine and for seven mines in the general groundwater area (encompassing some 1,116 square miles), and to develop postmining potentiometric surfaces in the coal aquifer and backfill. When only the one mine is considered, the model predicts that groundwater equilibrium will not be reestablished until over 100 years after mining has ceased. When all seven mines are considered, equilibrium conditions are met at different times for different mines, but are all in excess of 400 years.

The operator determined aquifer characteristics from drilling and pump-test data from 50 wells that occur in clusters on each mine site. Assumptions made for the entire model area included: coal and coal-parting material had a constant thickness, the coal outcrop was a no-flow boundary, and constant-head boundaries existed where streams eroded into the coal. Hydrologic conditions for the backfill (spoil permeability, postmining saturated thickness of spoils, spoil transmissivity) were estimated because data were not available.

To model the drawdown effects, a grid of nodes covering all of the area that might experience drawdown was established. The size of the grid system (31 by 36 blocks or 1,116 nodes) and the node spacing (one-mile centers) were chosen to fit the size of the proposed pits, the size of the area for which the applicant has data (there were good data for 11 of these 1,116 nodes), and the size of the area in which cumulative drawdown will occur. Implicit assumptions were that an active pit was equal in size to one grid block, that the entire block is mined simultaneously (in one time-step of the model), that the block was backfilled in the next time-step of the model, and that recharge to the backfill would begin at that time. The model simulated mining by reducing the potentiometric surface in the coal aquifer to the projected elevation of the bottom of the coal at that node, and decreasing transmissivity to approximate the effects of coal dewatering near the mine pit. Mine progression was simulated by lowering the potentiometric surface at different nodes during the corresponding time each block was to be mined. The effects of backfill on groundwater flow were simulated by changing the aquifer characteristics at the appropriate nodes, using the previously established spoil permeability.

Calibration of the model involved adjusting groundwater recharge and discharge rates from the coal aquifer at several locations (e.g., small lakes, closed depressions, and stream-discharge points) until the calculated premining groundwater levels in the coal closely matched those observed in monitoring wells. After calibration, the operator performed a sensitivity analysis to determine how the model responds to changes in the major parameters of transmissivity, storage coefficient, and head in order to evaluate the accuracy of the assumed values and to aid in making additional assumptions required in the operation of the model.

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[1] See case study mine L in reference 30.

Prediction of Postmining Impacts

After mining has been completed, the geological, geochemical, and hydrological elements have been altered. Aquifers have been disrupted, the overburden material has been broken up and mixed before being replaced as spoils, and sometimes "foreign" materials such as wastes from nearby powerplants are disposed of in the spoils. In order to assess the postmining impacts on groundwater, therefore, it is necessary to predict: 1) the nature and sources of spoils recharge, including postmining spoils aquifer characteristics; 2) the time of spoils resaturation and reestablishment of hydraulic equilibrium; and 3) postmining spoils water quality. Techniques for these predictions are summarized below; detailed descriptions may be found in volume 2.

The Nature and Sources of Spoils Recharge.—The principal sources of recharge are:

1. lateral recharge from adjacent, unmined strata (coal and overburden),
2. vertical recharge from underlying aquifers,
3. vertical recharge from surface infiltration, and
4. lateral recharge from surface water bodies in hydraulic contact with the spoils.

Box 6-E.—Use of the Trescott Model[1]

USGS used the Trescott model to simulate the effects of mine spoils on postmining groundwater flow of the Anderson-Dietz coal aquifer in the West Decker area of Montana. First, the area was divided into rectangular grids, and the grids aligned with the major and minor axes of hydraulic conductivity (coincident with cleats in the coal). Boundaries simulated fault zones, the Tongue River, the Tongue River Reservoir, head-dependent variable-flow boundaries, or constant-flow boundaries (see fig. 6-5). Water-level measurements were available for 92 wells, of which 68 were completed in coal, and the rest in scoria, interburden, overburden, and replaced spoils. Results of 16 aquifer pumping tests conducted in coal aquifers and six conducted in spoils also were available.

Premining steady-state calibration of the model was performed until it accurately simulated measured head distribution. Sensitivity analyses determined that the model is most sensitive to changes in hydraulic conductivity and least sensitive to changes in recharge, probably because of the localized extent of the recharge area. The sensitivity analyses also were used to determine future data needs: measurements of coal-aquifer hydraulic conductivity and the anisotropy ratio and of spoil-aquifer hydraulic conductivity.

With this model, USGS predicted that, at postmining equilibrium, water levels west of the West Decker Mine probably would increase almost 12 feet over premining levels, although the increases would diminish within several miles of the mine. These postmining increases were ascribed to the damming effect of the less permeable spoil on regional aquifer flow. The model also predicted that water would take about 13 years to flow from the spoils to the Tongue River Reservoir. Using the results of the flow model together with estimates of groundwater quality effects of mining, however, USGS predicted that the increase in dissolved-solids contribution to the reservoir due to mining would be less than 1 percent.

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[1] Adapted from reference 4.

If onsite data are available, recharge is determined relatively easily. For example, the Montana Department of State Lands studied spoils recharge at the West Decker and Rosebud Mines based on data from the mine permit applications plus data collected by the Montana Bureau of Mines and Geology. Representative monitoring wells in the coal and spoils aquifers for each mine were selected, and hydrographs utilizing all available water level data were plotted and analyzed to correlate water level changes with seasonal fluctuations and mining operations. From these data, it was determined that spoils recharge at the West Decker Mine comes mainly from adjacent, unmined coal beds that occasionally break the bed surface beneath the Tongue River Reservoir. Secondary sources are the underlying, unmined coal beds. Surface infiltration is considered insignificant due to the thickness and fine-grained texture of the spoils. At the Rosebud Mine, recharge is predominantly from adjacent unmined coals, but in localized areas, surface recharge is enhanced by thin spoils, coarse-textured spoils, and surface water bodies (30).

Without field data, groundwater recharge is difficult to quantify because it is a function of the spatial and temporal distribution of precipitation, topography-runoff relationships, and the unsaturated and saturated hydraulic properties of a spatially heterogeneous geologic environment. Where onsite data are not available, a water budget approach can be used to calculate recharge from surface infiltration. Box 6-F illustrates the use of this approach to predict spoils recharge for the purpose of permitting subgrade disposal of utility wastes in mine spoils (see also ch. 3, box 3-J).

Most mines have devised monitoring programs that may help quantify recharge to the spoils (see ch. 5). At a mine in Montana, where well data from resaturated spoils are available, the reestablishment of groundwater flow was predicted by comparing the hydraulic conductivity values from tests of spoils wells with those from tests conducted with wells in bedrock aquifers.[9] From the comparison, the operator was able to demon-

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[9] See case study mine F in reference 30.

Box 6-F.—Use of a Water Budget Approach To Estimate Spoils Recharge[1]

At a mine in Colorado, the operator calculated a monthly water balance for a soil zone 4 feet deep (measured from the surface) in order to determine the potential for surface recharge within the spoil zone where utility wastes would be buried. Data inputs for the water budget included monthly precipitation from historic records; calculated potential evapotranspiration rates; estimated surface runoff coefficients ranging from 0 to 0.25; infiltration rates of the surface soils determined from double-ring infiltrometer tests; and soil moisture-holding capacities predicted from textural analyses of the soil types. For each month, the amount of precipitation in excess of runoff was calculated and assumed to be available for infiltration. If this amount was less than or equal to the infiltration capacity, it became available for either storage in the soil (during winter months) or evaporation (during summer months). The soil moisture storage was increased or decreased incrementally depending on whether infiltration and accumulated soil moisture storage exceeded the evapotranspiration rate or vice versa. Water was available for downward percolation in any month when the accumulated moisture in the top 4 feet of soil exceeded the storage capacity of the soil. The analysis predicted that, during a typical year, no deep percolation through the spoils from precipitation infiltration would occur.

During very wet years, infiltration could exceed the soil moisture storage capacity and thus provide a potential for percolation below the 4-foot zone. Using the previous 35 years of weather data to estimate the probability of deep percolation, the applicant determined that the average percolation rate is approximately 1.6 cm per year (or about 4 percent of mean annual precipitation). Under these conditions, from 500 to 1,000 years would be required for percolating water to reach the saturated zone. Moreover, very little of the percolating water was predicted to reach the utility waste because the water would flow down the path of least resistance—in this case, the spoil material, which is 10 to 100 times more permeable than the waste material.

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[1] See case study mine P in reference 30.

strate that the spoils were approximately as transmissive as the coal aquifers they replaced, and that the reclaimed mine area would not cause obstruction of regional groundwater flow.

Some research is being conducted to validate methods for identifying specific sources of recharge. One study at the Center Mine in North Dakota was successful in isolating the various sources of spoils recharge by analysis of stable isotopes of oxygen and hydrogen in the water (11). However, this is not a technique that can be applied readily to other mining situations, because the isotope data indicated that the source of the water in the lower spoils at this mine was vertical infiltration from nonevaporative sites, predominantly during the period of spring snowmelt. Lateral inflow from adjacent mine pits or unmined areas is much more common.

Spoils Resaturation.—Spoils hydraulic characteristics, primarily permeability and porosity, determine the capacity of the spoils materials to store and transmit water. Unfortunately, **few field data on spoils hydraulics are available due to the youth of the Western surface mining industry** (see ch. 5). Therefore, permeability and porosity must be estimated analytically to predict the ability to restore premining storage and transmissivity.

Spoils aquifer characteristics are primarily a function of overburden lithology, especially the sand content of the rock, and mining method. Very fine-grained materials tend to have the highest porosity, but their permeability is very low due to the small particle size and the lack of interconnections between pores. The presence of a rubble zone at the base of the spoils also can increase hydraulic conductivity. When overburden aquifers occur chiefly as small, discontinuous sand lenses within a large matrix of clays and shales, the postmining spoils probably will have low permeability. The equipment selected and the mining configuration determine the degrees of swell, mixing, and compaction of the spoils that will occur (see ch. 3). The increase in volume due to swell factor increases porosity, which in turn increases permeability if the pores are sufficiently large and interconnected.

Where pump tests have been conducted in resaturated postmining spoils, hydraulic conductivities and storage coefficients of the spoils can be measured directly. Otherwise, the time required for recharge is predicted with estimates of spoils hydraulics and groundwater modeling studies. Due to the low permeability of spoils material throughout the Eastern Powder River basin, operators there have estimated that it could take from 70 to 2,900 years, depending on the recharge rate, for replaced spoils aquifers to reach a steady-state condition in which groundwater flow patterns are reestablished (34).

Postmining Spoils-Aquifer Water Quality.—One of the potential impacts after surface coal mining is a change in the quality of groundwater because the backfilling of overburden material results in the exposure of fresh mineral surfaces and provides an opportunity for chemical reactions. In the Western United States, the primary groundwater contamination problem resulting from these reactions is the elevation of total dissolved solids (TDS) levels in spoils groundwaters—primarily dissolved sodium, calcium, magnesium, and sulfate. It has not yet been determined whether acidity will be a problem for revegetation in postmining spoils (see ch. 8).

The magnitude of postmining groundwater quality impacts is highly variable, depending on the quality of groundwater entering the spoils, the amount of recharge from precipitation that has reached the water table, and the type, distribution, and leachability of spoils materials through which groundwater or precipitation percolates. The length of time required for spoils to become fully resaturated and groundwater flow patterns to be reestablished also will affect the timing and magnitude of impacts, but also will mean that there may be no way to verify the predictions by comparison with actual results. As a result, the validity of the predictions takes on a greater importance. Unfortunately, there is little agreement as to the best method for producing consistent, valid predictions. Furthermore, generalizations are not readily made from one mine to another, because geochemistry is highly site-specific.

Two general approaches are used today to predict spoils water quality. One involves measuring water-soluble constituents in the spoils and relating those values to observed spoils water quality at the mine site. The second is based on deterministic modeling of the chemical processes responsible for the evolution of spoils water quality, which is the basis for calculating the ultimate water quality.

The measurement and extrapolation method assumes that spoils water quality is largely a function of readily soluble constituents in the spoils that may be leached easily by groundwater. Batch-leach tests, saturated-paste extract analyses, or column-leach tests are the methods used most frequently in the West.[10] All three require sampling and chemical analysis of overburden and interburden materials from the mine area. Tests comparing the data from these methods indicate that their results are very similar. Column-leach tests are the most expensive, however (see box 6-G).

Predictions based on batch leaching of overburden samples can be made in the absence of any field data from resaturated spoils. However, the samples of water and overburden selected for the test may not be entirely representative of postmining spoils conditions—at best a few pounds of material are being tested to make predictions about hundreds of millions of tons of spoils—and the mixing ratios and contact times used for the test may not represent actual conditions. The samples of overburden selected for the test usually represent a worst case of material potentially detrimental to water quality; then, for comparison, the test also is run on samples of "suitable" or average overburden material. Therefore, the predictions of postmine spoils water quality from this test will be conservative. Batch-leach tests were used by the USGS to simulate changes in groundwater quality that may occur as a result of mining operations in the West Decker area in Montana (4).

Saturated-paste extract tests are especially useful where spoils water data are available because a statistical correlation can be derived between

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[10] See reference 30 for a detailed description of these techniques and their application.

Box 6-G.—Use of Column-Leach Tests[1]

The operator of this Colorado mine performed column-leaching studies to address concerns raised in a 1980 USGS technical analysis of the permit about the leaching of soluble ions from the spoil material. Overburden samples were collected over the property at a density of about one hole per square mile, and the geology of the overburden was assessed. Overburden leaching columns were placed in cylinders, with tap water applied to the top of each cylinder to maintain a constant head. When the leachate began to flow out of the bottom of the cylinder, the instantaneous electrical conductivity (EC) and the cumulative weight of the leachate were measured at specific time intervals. The readings were terminated when the volume of the leachate exceeded the volume of the sample. The final, cumulative leachate from each column was analyzed for EC, TDS, pH, iron, manganese, sulfate, calcium, bicarbonate, magnesium, sodium, potassium, and chloride. A relationship between TDS and cumulative leachate volume was developed for each column. The study also provided a means to estimate postmining groundwater quality and the time that will be required for the spoil water to return to baseline TDS concentration.

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[1] See case study mine O in reference 30.

the predicted water quality and actual analyses of spoils water. For this reason, this method was used in a 1982 study of cumulative impacts for mines in the Tongue River basin of Montana and Wyoming, which estimated that dissolved solids contents in postmining groundwater would increase between 63 and 300 percent. Sodium, sulfate, and bicarbonate concentrations were predicted to increase the most (25).

Typically, when any of these three methods is used to predict postmining spoils water quality, spoils recharge subsequently is monitored, and the spoils water quality sampled as resaturation occurs. Such monitoring programs should contribute information to allow the verification of assumptions made about the trend of spoils water quality over time (and the time frame in which recharge will occur). Monitoring will not always provide direct information on postmining groundwater quality, however, because it cannot be assumed that the monitoring will be continued for the centuries predicted to be required for groundwater systems to establish a postmining equilibrium.

Predictive modeling methods are under development that could estimate changes in groundwater quality based on statistical analyses of geochemical trends. The USGS currently is working with three process-oriented deterministic models of the chemical processes occurring in and downslope from the spoils, of recharge to the spoils, and of water movement through the spoils (28). The three models are: WATEQF, BALANCE, and PHREEQE.[11] Data from coal mines in Wyoming are being used to test the modeling concepts, and one of the large mining companies currently is using these models to try to understand the geochemical reactions that are resulting in undesirable spoils-water chemical characteristics at a mine in the Powder River basin of Wyoming. It must be kept in mind, however, that as with the groundwater models discussed previously, the results of these predictive water quality models will only be as good as the input data and assumptions.

Researchers at the North Dakota Geological Survey are using computer methods to develop a comprehensive hydrogeochemical approach to the prediction of spoils water quality, because they believe that the saturated-paste extract method estimates only the short-term spoils water quality, and ignores the long-term salt generation capacity. The researchers concluded that, in order to assess the chemical conditions on a long-term basis, it will be necessary to develop analytical techniques to determine calcite content at very low levels of concentration, abundance of potentially oxidizable pyrite, and actual ion-exchange characteristics under field conditions (15). The work probably is only applicable within the Fort Union mining region (see box 6-H).

Predicting the Impacts of Powerplant Waste Disposal.—At some mines in the West, ash and sludge from mine-mouth powerplants are disposed of in the mine backfill. The analytical tech-

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[11] See vol. 2 for detailed descriptions of these models.

Box 6-H.—Deterministic Model Development in North Dakota[1]

The term "engineered cast overburden" (ECO) was coined in North Dakota to refer to an approach to reconstruction of the entire landscape rather than just its surface form and soil. This approach to postmining groundwater chemistry requires a thorough understanding of several geochemical and mining processes as well as the development of a number of analytical techniques. Soil mapping, geologic mapping, development of a three-dimensional materials framework, geohydrological studies, and geochemical studies are conducted to define the properties of overburden materials. An understanding of the form and internal structure of material deposited by various types of mining equipment and techniques also is necessary to determine which equipment and procedures produce desired physical and chemical characteristics at appropriate locations within the cast overburden.

The analysis assumes that a model that adequately represents observed water chemistry in the premining overburden will be reliable for predicting postmining water chemistry. The model must account for several variables, including the predominant ions in the groundwater, the pH of the water, variations in the concentration of TDS of the groundwater, and the partial pressure of dissolved carbon dioxide in the water. It also must account for water chemistry changes that occur as the water infiltrates and migrates through the underlying unsaturated zone into the groundwater zone.

ECO studies resulted in the development of a hydrogeochemical model that accounts for the observed chemical characteristics of subsurface water in both disturbed and undisturbed settings. Critical hydrogeochemical processes were determined to be sulfide oxidation, gypsum precipitation and dissolution, carbonate mineral dissolution, and cation exchange. Major species of concern are sodium and sulfate. Sulfides are the major source of sulfates, and the solubility of sulfate in groundwater was determined to be largely controlled by the sodium/calcium ratio. Alternate wetting and drying in the near-surface landscape was found to be a key mechanism in hydrogeochemical evolution. The worst impacts on postmining groundwater quality were predicted to result from placement of unoxidized sodic and sulfide-rich sediments near the surface and above the water table where water from surface infiltration could contact them en route to the groundwater table. Placement of these materials below the postmining water table can result in short- degradation of groundwater, but over the long term will prevent oxidation of the sodic and sulfide-rich sediments and water quality will improve after initial flushing of soluble salts. This modeling technique allowed the investigators to predict both short- and long-term effects of mining on the groundwater quality, and if the modeling and input assumptions are correct, the predictions should be valid (input assumptions can be tested as monitoring data are collected and used to verify the model).

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[1] See reference 30 at pp. 414-417, and sources cited therein.

niques used to evaluate potential impacts to groundwater quality at these sites utilize the various methods described above. The techniques used at one New Mexico case study mine are described in box 6-I (see also box 6-F, and ch. 3, box 3-J).

Predicting Surface Water Impacts[12]

Surface mining can affect surface water in several ways. During mining, streamflows can be reduced by the local lowering of the water table in the vicinity of the mine or by disruption of the aquifer (see fig. 6-1B). Natural flow also can be augmented by mine-discharge water, but usually the discharge is not significant in relation to the mean annual runoff volume of streams in the Western United States. More important in the West is the impact of mining-related augmented or diminished flows on surface water quality. In addition, both suspended and dissolved solid levels are often elevated, reflecting the higher rates of erosion and the higher availability of soluble cations often associated with any large earthmoving operation. After mining, as the hydrologic equilibrium is reestablished, few residual impacts on surface water quantity or quality are likely, although not enough time has elapsed at most Western mines to verify this assumption with monitoring data.

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[12] Unless otherwise noted, material in this section is adapted from reference 30.

Box 6-I.—Techniques for Evaluating Groundwater Quality Impacts From the Disposal of Powerplant Wastes[1]

Waste disposal at this New Mexico mine includes the burial of fly ash, bottom ash, and centrifuge sludge throughout the excavated portion of the mine area. A total of approximately 64 million cubic yards of powerplant waste will be disposed of in the backfill over the life of the mine. The operator assessed potential impacts to groundwater quality from mining and waste-disposal operations in two distinct efforts: laboratory studies, and groundwater-leachate transport studies. Laboratory studies were used to evaluate the potential chemical impact of spoil and waste materials on groundwater quality in the principal aquifer—in this case, the coal seam itself. Column-leaching studies used samples of the mine spoil material and a mixture of the mine spoil and the powerplant waste to simulate the impact on the quality of the groundwater as it flows through the two types of material. Groundwater-leachate transport studies calculated the migration by fluid flow of leachates through the backfill and estimated the time of reestablishment of the water table in the backfill. The transport studies were mathematically modeled using solute-transport equations. Worst-case assumptions were made for input parameters where data were unavailable. The time of reestablishment of the water table in the backfill was estimated with a computer model, based on widely accepted flow equations, that was developed for this study.

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[1] See case study mine R in reference 30.

The extent of surface water impacts depends on the premining hydrologic regime. Where mining is within the drainage basin of a perennial stream (e.g., the Yampa River of northwestern Colorado) with naturally high water quality, the potential impacts are likely to be greater and more widespread. Conversely, in a drainage system characterized by the more prevalent ephemeral streams, which flow only in response to runoff events and have naturally high sediment loads, impacts are locally confined and generally less significant.

Surface water impacts are readily observable, and analytical techniques for predicting these impacts are less hypothetical than those used for groundwater analysis. As with any analytical technique, however, the quality of the input data will determine the validity of the analytical results. As discussed in chapter 5, there are few reliable data on streamflow quality and quantity for ephemeral streams in the coal mining areas of the Western States. Because most of the surface water affected by Western mining activities is in ephemeral drainages, this lack of data is a constraint on the use of analytical techniques to design reclamation measures for the surface water resource.

Surface Water Quantity Impacts

Peak flows and low flows of streams are important characteristics in describing the hydrology of the general mine area, and thus in predicting the impacts of mining and designing reclamation (see below). Streamflow is derived from two components: base flow and direct runoff. Base flow is supplied by groundwater aquifers, while runoff is supplied by precipitation, snowmelt, and, in the case of surface mining, by mine discharges. Peak flows generally coincide with periods of peak runoff. Low flows coincide with periods of little or no runoff, when perennial streamflow is maintained by groundwater inflows.

The primary potential effect of mining on water levels in streams is a reduction in base flow in response to drawdowns in the water table caused by the cone of depression created around the mine pit. Because most of the streams directly affected by mining are ephemeral and thus have no base flow component, they are not affected by mining-related drawdowns, and individual mines have relatively little impact on the quantity of surface water supplies. Intermittent streams (which have seasonal flows) may be impacted to the extent of their base-flow component.

During seasons of high runoff or when groundwater intercepted by the pit exceeds onsite needs, water also will be discharged from a mine into area streams. The discharge may be temporary, intermittent, or continuous, and usually will be small in relation to the mean annual runoff volume of the receiving streams except when saturated scoria is intercepted. Short-duration, high-volume discharges are difficult to predict during mine planning, but in a water-short area no adverse impacts result provided the water quality of the discharge is within the range of the water quality of the receiving stream.

When mine discharges can be predicted, estimation of the resulting impacts on water quantity generally involves comparing the estimated rate of flow of the discharge to the range of natural flows typical for the receiving stream. If these are relatively equal, the discharge will not exceed the hydraulic capacity of the stream, and thus will not cause erosion downstream from the discharge point. This analysis can be done either using actual gage data, or with statistical or deterministic models.

The Log-Pearson Type III distribution method uses gage data to estimate the frequency (2 to 100 years) at which designated peak flows will be exceeded. Data collected over at least a 20-year period are required for meaningful results using this method. Although these data are available at some locations for all major perennial streams that may be affected by Western surface coal mining, they are rarely available for intermittent and ephemeral streams, unless mining has been conducted in the area for a long period of time.

Statistical Models.—USGS hydrologists, in the course of studying the hydrology of various drainage basins in the West, have developed multiple-regression equations for estimating flood peaks at ungaged stream sites. In general, the equations are a means of extrapolating, over a large area, correlations derived from data collected at a limited number of sites. Individual sets of equations are specific to a particular hydrologic region, and to drainage basins of a certain size. Application of statistical models generally requires only the use of a topographic map to determine drainage area, basin slope, maximum basin relief, and main-channel slope.

Deterministic Models.—Most rainfall-runoff models used by mine operators are based on the Soil Conservation Service (SCS) method of estimating direct runoff from storm rainfall, which in turn is based on the widely accepted unit-hydrograph theory (14). Input data on the vegetation and watershed characteristics of the drainage area, and on channel slope, relief, and soils are readily obtained from topographic maps, soils maps, and field observation. Data on precipitation frequency-duration relationships are available from published U.S. Weather Bureau and National Oceanic and Atmospheric Administration (NOAA) reports.

This method is calculation-intensive, and not easily used without a computer. Moreover, estimation of runoff volumes and peak discharge by these various deterministic methods can be considered more of an art than a science. Even using the same method, it is probable that two independent investigators will achieve different results because the assumptions that must be made about the hydrologic regime of the site will influence the input parameters and therefore the results.

Surface Water Quality Impacts

Both direct runoff and groundwater discharges to surface streams can have high TDS and/or TSS levels, depending on the medium the discharge is flowing over or through and the rate of flow, among other variables. Elevated TDS concentrations usually result from groundwater discharges, but normally are not included as limiting parameters in discharge permits because of the difficulty of controlling them. Increases in TSS levels are more likely to result from runoff and subsequent erosion, and are controlled with sediment control structures (see below). Peak flows typically coincide with low TSS levels due to dilution, while low flows coincide with high TSS. Low-flow values usually are used to quantify the worst-case stream water quality degradation that may occur in perennial streams.

In the absence of site-specific data (the usual case), the amount of sediment that will erode from a watershed and be subject to transport downstream during a precipitation event generally is estimated using the Universal Soil Loss Equation (USLE), developed and calibrated by the Agricultural Research Service. With limited data, the strength of USLE lies in its ability to provide relative estimates for comparison of alternative projects, rather than absolute determinations.

Prediction of Cumulative Hydrologic Impacts

CHIAs of all ongoing and anticipated mining in a permit area are mandated in section 507 of SMCRA. CHIAs are conducted by the regulatory authority based on the PHC determinations submitted in permit applications and other data available from Federal and State agencies. A CHIA must be for the proposed life of a mine, including the time needed to achieve permanent steady-state after mining. It is intended primarily to demonstrate that the proposed mining activity, when added to all other mining activity in the region, will not materially damage the hydrologic system outside the mine permit area.

Depending on the availability of data and the impacts of concern, a CHIA may emphasize either the full range of potential hydrologic impacts or only specific sets of impacts. For example, while each operator in the Powder River basin of Wyoming is required to submit a comprehensive PHC determination to address all components of surface and groundwater hydrology, the CHIAs that have been conducted in this region were concerned primarily with cumulative impacts to groundwater flow, cumulative drawdowns from mine dewatering (see box 6-D), and the cumulative impacts of sedimentation control (see ch. 8).

The interpretation and implementation of the Federal law as it pertains to PHCs and CHIAs is the subject of considerable controversy. As discussed in chapter 4, recent Federal court decisions remanded to the Department of the Interior regulations on whether a PHC determination should cover the 5-year permit area or the life-of-mine area. The court also found DOI's definition of "anticipated mining" for CHIAs to be inconsistent with SMCRA.

A reasonable cumulative assessment of impacts to the various components of the hydrologic system over the life-of-mine area can be made at most Western surface coal mines using some combination of the available analytical techniques already described for surface and groundwater systems. As discussed above, however, none of these techniques is a perfect indicator of hydrologic impacts.

The principal limiting factor to the predictive capability of all of the techniques is the availability of reliable data. In the case of certain techniques, the lack of site-specific data can be accommodated (e.g., techniques that predict hydrologic responses based on assumptions derived from widespread but relatively sparse data, such as the flow-estimating techniques based on statistical models). In other instances, the data required to perform one analysis of impacts over the life of the mine must be obtained using many other techniques, sometimes at prohibitive expense. For some analytical techniques, however, the data often are not obtainable for term-of-permit assessments, much less for a life-of-mine assessment (e.g., spoils water quality determinations in areas where recharge is predicted to take centuries).

The built-in errors associated with inadequate data or with the need to make assumptions are accommodated through regulatory requirements for worst-case analyses. So, as uncertainty about the system increases, assumptions made for input to the various analytical techniques become more conservative. Although this strategy avoids errors from underestimating the potential hydrologic impacts, it may entail other consequences resulting from overstatements of those impacts, including increased reclamation costs.

Another important limiting factor is the incomplete knowledge of some of the geochemical processes occurring in the postmining spoil, which makes it difficult to express these processes mathematically. This problem is exemplified by the current controversy over the correct methodology for predicting the potential for acid-formation in Western mine spoils (see ch. 8).

One possible approach to the problem of conducting CHIAs is to use repermitting data—the data submitted by active mines every 5 years to support applications for permit renewal—to recalibrate the models used for the CHIAs and to assess the validity and sensitivity of the various input assumptions. Periodic sensitivity analyses of the variables would provide valuable information about data inadequacies and could be used to focus industry and Federal and State agency data collection efforts (see ch. 5).

PHCs and CHIAs can be accomplished with or without a computer, but the use of computer modeling appears to be a more efficient way of assessing the complex hydrologic problems that must be addressed in a cumulative analysis. Examples of both methods of analysis are discussed in box 6-J. More detailed information about specific data requirements and the analytical techniques used in these examples can be found in volume 2.

Predicting Impacts to Wildlife[13]

Quantitative techniques for predicting the impacts of surface coal mining on wildlife *populations* have not been found to be effective and are used infrequently. One constraint on such techniques is data inadequacy (see ch. 5). Moreover, while the basic responses of wildlife to environmental factors are often easy to analyze and predict intuitively, it is difficult to quantify this sort of analysis. It is even more difficult to segregate sources of influence on the populations or variation in the environment to determine which factors have caused what percentage of the observed effect. **Consequently, wildlife impact assessments generally are made by intuitive professional judgment, based on a knowledge of the mining operation and the ecology of the affected area.**

Although numerous baseline and monitoring data are collected on wildlife populations to determine patterns of wildlife use of the mine site and adjacent areas, these data generally are perceived as unreliable and typically are not analyzed statistically (see ch. 5). Instead, the data are reviewed by industry and agency biologists who look for trends from which they can interpret habitat affinity and predict the impacts of habitat disruption. These qualitative or intuitive impact assessments involve comparing available data with the characterization and analysis (often quantitative) of wildlife habitats. Such indirect assessments of impacts to habitat quality may be more meaningful in terms of predicting the ultimate impacts of mining to wildlife (box 6-K; see also ch. 3, box 3-G).

Box 6-J.—A CHIA of the Yampa River Basin[1]

The coal mining areas of the Yampa River basin in northwestern Colorado contain several important perennial streams, and the water quality of those streams is subject to degradation as the overburden and coal aquifers that contribute to base flows are replaced with mine spoils. Eventually, these mine spoils will leach water with elevated TDS relative to the undisturbed aquifers. A 1982 CHIA of this region did not use computer modeling methods, and so was only able to estimate mining-related changes in TDS concentrations for two cases, as opposed to the infinite number of cases that can be computer simulated. The two cases chosen were the historic low flow (representing the worst case) and the mean flow. Other limitations of the method were the difficulty in using available data because of nonstandard collection methodologies and reporting procedures, and the lack of flexibility and complexity in the mathematical basis of the model. In 1983, a computer model for a portion of this same basin was developed by USGS for use by the Colorado Mined Land Reclamation Division (MLRD) in evaluating potential cumulative surface water impacts of proposed mines. The model is based on a more complex algorithm that enhances its flexibility with respect to simulating various mining scenarios. As with most computer techniques, the limiting factor is availability of reliable input data. Analytical results are only as valid as the various methods for estimating, interpolating, and extrapolating input data where measured data are lacking.

[1] Adapted from reference 30.

OSM recently funded a study to evaluate quantitatively the effectiveness of mitigation measures practiced at coal mining operations in the Western States (20). This study, using multiple linear regression analyses, assessed the relationship between various wildlife populations (mammals and birds, both large and small) and the biological and

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[13] Unless otherwise noted, material in this section is adapted from reference 2.

Box 6-K.—Analysis of Wildlife Data for Wetlands Restoration[1]

In central North Dakota, intensive agricultural practices have eliminated most native wildlife habitats, displacing wildlife species native to undisturbed northern prairies. Prairie-potholes, a specialized wetland habitat, are an exception. The operator of a large lignite mine proposed to mine through and then reestablish some of these wetlands, an unproven concept. The regulatory authority required the operator to collect intensive baseline wildlife data, which included inventories of all species groups known to exist in the mine area by habitat type and by season. The only wildlife data actually used to predict the impacts of mining and to formulate reclamation plans and monitoring procedures were those for waterfowl and aquatic species; otherwise, habitat-classification data were more useful. It is possible that both the wetland-related data and other wildlife data will be used at some future date to perform a detailed impact assessment and evaluation of the operator's success in restoring the wetlands and their indigenous wildlife. However, both mine and regulatory personnel believe that future baseline data collection efforts should concentrate on the characterization of habitats and the evaluation of special characteristics of critical habitats, rather than on extensive inventories of wildlife populations.

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[1] See case study mine A in reference 2.

physical features of reclaimed areas. Wildlife responses to 28 predictor and 17 response variables were analyzed at four mines. Wildlife variables such as species diversity and abundance were compared to habitat variables such as shrub cover, distance to water, and undulating topography. One of the principal conclusions of this study was that wildlife responses to various habitat features and configurations were largely consistent with intuitive professional judgments regarding the effectiveness of commonly recommended mitigation practices. The study, therefore, reinforces the validity of a subjective versus a quantitative approach to wildlife impact assessment.

Today, no discipline can escape the inexorable advance of the use of computers for data analysis. This is true even in the field of wildlife biology, where valid data are not easily obtained. At one mine, Los Alamos National Laboratory was contracted to perform computer-analyses of wildlife data.[14] The extent of the computer assistance was to expedite the plotting of big game movement information on maps, which usually is done by hand. Another computer application attempted to choose an appropriate population estimation model for the small mammals and then estimate population sizes. This attempt was unsuccessful due to insufficient data, and exemplifies the inherent problems involved with accurate prediction of many wildlife populations.

Another use of computers to evaluate wildlife data is the U.S. Fish and Wildlife Service's Habitat Evaluation Procedures (HEP) program. HEP was developed to provide a standardized approach to evaluating wildlife impacts based on changes in habitat quality values. Habitat quality for selected species is evaluated with an index value obtained for individual species from habitat suitability models (over 80 published) employing measurable key habitat variables. Index values are multiplied by area of available habitat to obtain Habitat Units for individual species. Index and habitat unit values derived for land prior to and after disturbance are used to provide a quantitative measure of the impact to wildlife habitat. The more that is known about habitat requirements of the various indicator species, the more accurate is the rating scale developed to measure habitat quality.

As with any impact prediction methodology, HEP's ability to provide accurate projections of the magnitude of future impacts can be no better than the user's ability to predict habitat conditions subsequent to disturbance. However, HEP does provide a quantitative mechanism for performing projections of the severity of impacts resulting from habitat disturbance. HEP has been used extensively for water development projects where the extent of temporal and spatial habitat loss can be documented. As yet, however, only a few attempts have been made to use HEP for projecting wildlife impacts related to Western surface coal mining disturbances.

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[14] See case study mine G in reference 2.

Predicting Revegetation Success[15]

The impact of surface mining on plant life is immediate and predictable: with few exceptions, once the soil is removed from a mine site the original vegetation has been destroyed. Therefore the primary emphasis is on devising methods to predict the long-term impacts, or revegetation success. The success of a given revegetation technology or method is assessed qualitatively based on a comparison of data from different reclaimed areas.

This qualitative method for predicting revegetation success at a particular location considers the results of the most recent revegetation methods at other mining operations in the region which have similar soil, overburden and climatic characteristics. In the comparison, it is assumed that given similar environmental factors, the results of particular reclamation technologies also will be similar. This case-by-case approach is essentially the technique used by State regulatory personnel when making their technical evaluation and analysis of permit applications. It also is the basic technique available to agencies such as the Bureau of Land Management (BLM) for impact prediction in environmental impact statements. Although this type of analysis does not lend itself to a rigorous mathematical treatment, the lack of a quantitative model for predicting reclaimability does not appear to diminish the potential for accurate prediction.

One quantitative model for predicting revegetation success was developed in the study region. It used data collected in 1976 and 1977 on sites revegetated under pre-SMCRA requirements as well as from unmined areas (18). This model assumed three factors to be driving (independent) variables: annual precipitation, growing season length, and the age of revegetation. The dependent variables were cover and production. Woody plant density and lifeform or species diversity were not addressed. Because the baseline data were collected from areas revegetated pre-SMCRA with what is now considered somewhat primitive technology, they form a poor basis for predicting success with current technology. The authors of the model acknowledge that the baseline data are weak in many respects, and that variations in cultural treatments and the young age of most of the revegetation samples confound potential conclusions from the data. Without further development of the model and improved data inputs, it is doubtful it could be useful in current revegetation analyses.

ANALYTICAL TECHNIQUES USED IN THE DESIGN OF RECLAMATION

Because techniques for predicting the various impacts of mining are imperfect, and because in many instances reclamation results cannot be observed directly (e.g., groundwater aquifer restoration where recharge is measured in centuries), the analytical techniques used to design reclamation are critical to reclamation success. The reliability of these techniques is especially important when the evaluation of reclamation success is based on design, rather than performance, standards, given the uncertainty about who is responsible for design failure. The most important design elements for the ultimate success of the reclamation plan are: 1) accurate characterization of the overburden and delineation of overburden material potentially detrimental to groundwater quality or revegetation, 2) optimization of soil salvage, 3) well-stabilized stream channels, and 4) efficient sedimentation control. This section discusses the analytical techniques used to design these components of the reclamation plan, plus the design and reclamation of alluvial valley floors.

Overburden Characterization and Reclamation Planning

After the coal has been extracted, the overburden and interburden form the basic material for reclamation, and the chemical and physical character of these materials are major factors in determining the impacts of mining on postmining spoils hydraulics and water quality (16). In actuality, the geology of the overburden in many of the mining regions of the West is so complex that it is usually not practical (and often infeasible) to define the overburden in great detail. As a result, gross characterization of the overburden is the basis for the design of the earth-moving portion of the reclamation plan of many surface coal mines in the West (see ch. 5).

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[15] Unless otherwise noted, material in this section is adapted from reference 28.

The objectives of methods used in characterizing the overburden are to determine its physical and chemical character in order to evaluate reclaimability; to estimate the volume and location of different types of overburden material; and to design a backfill plan that achieves chemical and physical stability and approximate original contour. Table 6-3 shows the current criteria for overburden unsuitability for three of the five States (Colorado and New Mexico have no formal unsuitability criteria for overburden). These criteria are referred to as "suspect levels." If prescribed laboratory techniques show overburden components to be above these suspect levels, the components may be considered unsuitable if replaced in reconstructed root zones or where they might contaminate surface water or groundwater supplies.

Table 6-3.—Overburden Unsuitability Criteria by State

Parameter	Montana (DSL 1983)	New Mexico (MMD 1984)	Wyoming (DEQ 1984)
pH acid	<5.5	<6.0	<5.0
pH alkaline	>8.5	>9.0	>9.0
EC (mmhos/cm)	>4.0-8.0	>16.0	>12.0
Texture	excessively clayey, silty or sandy	none given	none given
Sat %	<25% >85%	none given	none given
SAR	none given	>12.0 >15.0 >20.0 depending on texture	>12.0 >15.0 depending on texture
ESP	>15.0 >18.0 depending on texture	none given	none given
B	>5.0 ppm	>5.0 ppm	>5.0 ppm
Se	>0.1 ppm	>0.5 ppm	none given
ABP	none given	0 tons $CaCO_3$ equivalent/ 1,000 tons	< −5 tons $CaCO_3$ equivalent/ 1,000 tons
Mo	>0.5-1.0 ppm	none given	none given
Organic carbon	none given	none given	>10%

SOURCE: James P. Walsh & Associates, "Soil and Overburden Management in Western Surface Coal Mine Reclamation," contractor report to OTA, August 1985.

Unsuitable overburden can be categorized in one of two ways, depending on the mode of occurrence:

- *Type 1:* Mappable strata (e.g., carbonaceous shales, pyritic sands) that occur over more than 25 percent of the mine site, are predictable in occurrence, and generally are regarded as uniformly deleterious to root growth and/or groundwater; or
- *Type 2:* Unmappable pods of unsuitable material, usually exhibiting elevated levels of trace metals (e.g., arsenic, boron) that are not readily predictable in occurrence. While they may occur only in one particular strata or lithotype, the occurrence is not uniform or the associated rock units are not mappable with the density of drillholes which can be reasonably required (17).

While there are no standardized methods for the interpretation of overburden data, there are several methods that seem to be commonly used to characterize the geochemistry of the overburden and define volumes of potentially deleterious material. These techniques usually are repeated and refined as additional data are collected in potentially unsuitable areas. The methods described below are illustrative of the varying degrees of qualitative versus quantitative analysis possible, and are not intended to be a comprehensive listing of methodologies.

One approach is the use of classical statistical analysis to determine a thickness-weighted mean, standard deviation, and range for each parameter in the overburden database. However, a statistical analysis may not be valid for some parameters (e.g., pH, which is a logarithmic function). Moreover, this approach does not include the correlation of geochemical values (laboratory data) to individual rock strata in the overburden, nor does it provide a way of determining either the total volume of potentially deleterious material or the position of that material within the overburden. Rather, this technique assumes that perfect mixing of the overburden is achieved with whatever mining and backfilling techniques are proposed. Therefore, the technique seems to be valid only for the broad characterization of overburden over the mine-site. Under certain conditions, such as when all of the overburden is considered suitable or unsuitable, this level of analysis is adequate.

Other methods of characterizing overburden must be employed in the more common situation of overburden that is only partially unsuitable. With such overburden, it becomes important to determine both the volume and location of the unsuitable material (given the modes of occurrence listed above). The same classical statistical analysis can be used if the overburden data are segregated into data sets representing individual mining benches. The underlying assumption for this technique is that, during mining, perfect mixing of the overburden will occur *within each bench*. In general, this approach is valid for demonstrating that an individual bench is either entirely suitable or unsuitable. This approach also can be used reliably if the unsuitability is specific to either the vegetation or the groundwater resource, and it can be demonstrated in the mining plan that the unsuitable bench will be placed in the backfill such that it will not be in contact with the resource to which it is deleterious.

It is unusual, however, for all of the material in a bench to be of uniform suitability. Many regulatory authorities have adopted a working assumption that if the unsuitable overburden comprises less than a certain percentage of the total overburden by mining bench,[16] it will be mixed adequately with suitable spoil material and no vegetation or groundwater problems will arise in the backfill. Based on field studies and empirical observations, the cut-off has been set at 15 percent unsuitable material for dragline operations and 20 percent for truck and shovel mines (5). Several operators of large truck and shovel mines in the Powder River basin of Wyoming are presently conducting mixing studies to refine these estimated mixing ratios.

If the unsuitable strata are mappable (type 1), this bench method of overburden characterization is adequate if it can be demonstrated that the unsuitable material constitutes less than the cut-off percentage. Ideally, this demonstration can be made (either manually or by computer) by correlating the unit in question from all available geologic information, mapping the extent and thickness of the unit, and then comparing this elevation and thickness projection to the elevation and thickness of the proposed mining benches. Using the correlations, one can determine the location and extent of areas where the unsuitable stratum represents a greater percentage of the bench than is permissible. In practice, however, more subjective and cost-effective techniques relying on professional expertise often are employed.

If, on the other hand, the unsuitability is unmappable (type 2), and a correlation between the occurrence of the unsuitability and a geologic feature cannot be found, the bench method must be modified further. This technique incorporates the proposed mining-bench configuration but more or less ignores the stratigraphy of the overburden. Data from each drill hole are grouped by mining bench, and the percent unsuitable material, weighted by sample thickness, is determined within each data group. Finally, the area of influence of each drillhole is determined, usually by the conservative polygon method of interpolation.[17] Maps are generated to portray graphically the limits of potential unsuitability for the mine permit application (see fig. 6-5). Generally, the analysis is performed manually because it is as accurate as and less time-consuming than using a computer.

This last method of overburden characterization is becoming common in Wyoming, where most of the mines are large and where the State regulations and guidelines, by virtue of their level of detail, promote conformity among the permit applicants by emphasizing design standards. In other States, methods for characterizing the overburden generally are more empirical or intuitive. In Colorado, for instance, the regulatory authority regularly receives and reviews uninterpreted

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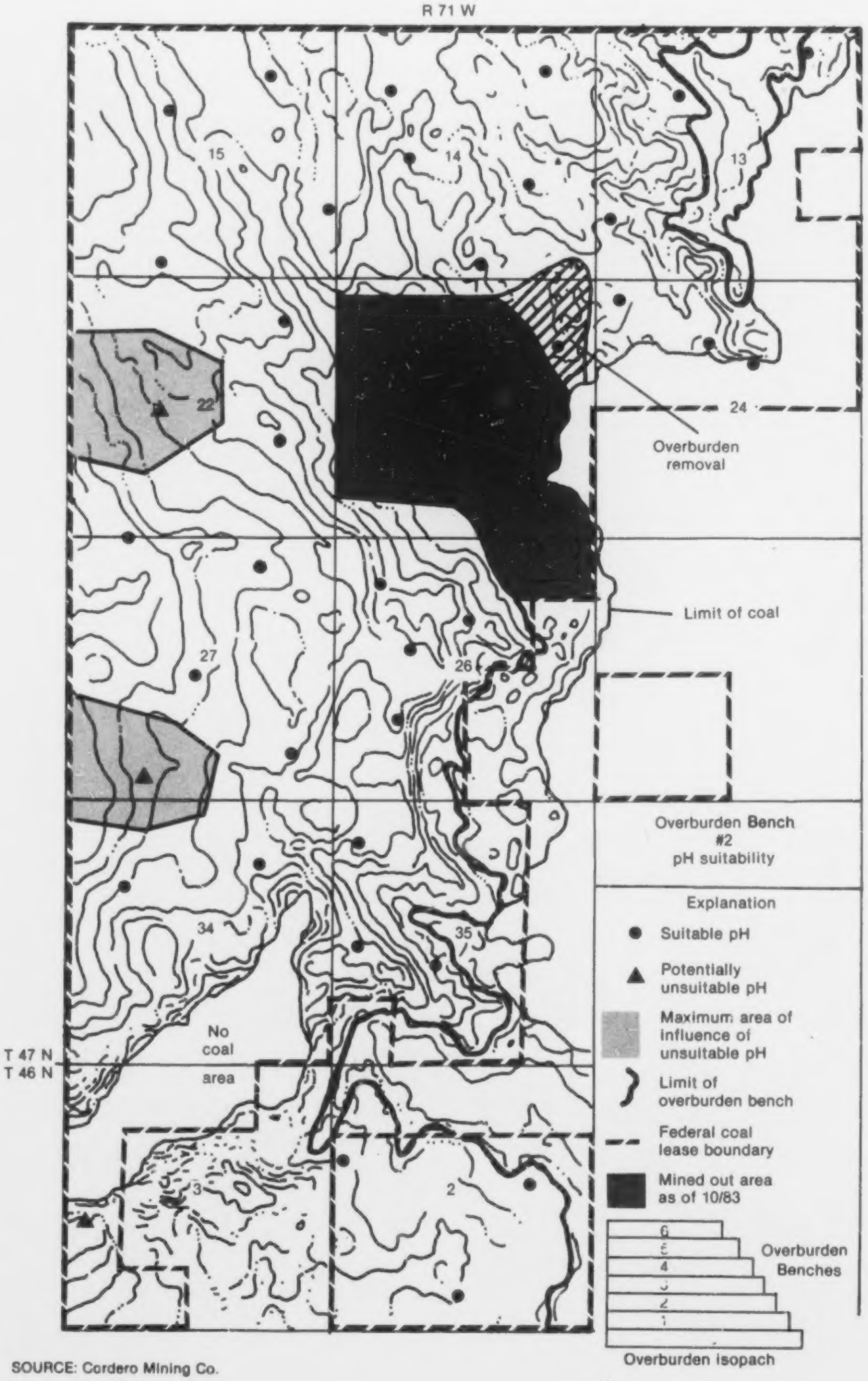
[16] One bench is assumed for a dragline operation, while the number of benches in a truck and shovel operation will vary with the thickness of the overburden.

[17] A method by which the area of influence of each drillhole is defined by connecting a series of lines drawn around that hole bisecting the distance between that hole and the next adjacent hole so that the resultant area is polygonal in planview.

Figure 6-5.—Overburden Bench Suitability


R 71 W
15
14
13
22
24
Overburden removal
Limit of coal
27
26
34
35
No coal area
T 47 N
T 46 N
3
2
Overburden Bench #2 pH suitability
Explanation
● Suitable pH
▲ Potentially unsuitable pH
Maximum area of influence of unsuitable pH
Limit of overburden bench
Federal coal lease boundary
Mined out area as of 10/83
6
5
4
3
2
1
Overburden Benches
Overburden isopach

SOURCE: Cordero Mining Co.

laboratory data (3). To the extent anomalous data are found, the operator is asked to provide additional data or analysis to further define the unsuitability.

Once the nature and extent of the overburden unsuitability is defined, the operator and the regulatory authority can agree on the best method of mitigation. In most cases, the operator must selectively place unsuitable materials 4 to 8 feet below the ground surface, and away from reconstructed stream channels. Special handling of unsuitable material may also be required to keep the material out of the root zone or groundwater recharge zones (see ch. 3, boxes 3-C, 3-H, and 3-J). For unsuitable material exhibiting parameters that are not mobile under reducing conditions, there is some debate about whether the material should be placed above or below the postmining water table to prevent the entry of undesirable elements into the groundwater system. The practicability and/or cost-effectiveness of selective placement generally are a function of the type of mining equipment used (see ch. 3).

Soil Characterization and Reclamation Planning[18]

The redressed soil serves as a chemical and physical buffer between the backfilled mine spoil and surface water, vegetation, and wildlife resources, and therefore is a critical element in successful reclamation. In designing soils reclamation, the objective is to determine which materials will be salvaged for use as topdressing over the postmining recontoured spoil surface. The three steps involved in planning soil reclamation are: 1) determining the premining physical and chemical character of the soil (see ch. 5); 2) estimating the total volume, the "suitable" volume, and the final redressed thickness of the salvageable soil resource; and 3) designing a redressing plan to ensure chemical and physical stability of the postmining soil. Each State has soils unsuitability criteria (see table 6-4). Differences among the State criteria reflect differences in reclamation objectives or emphasis, as well as in professional judgment and interpretation among the technical staff.

Determination of salvageable soil is usually accomplished by direct comparison of physical and chemical parameters of individual map units with State unsuitability criteria. For example, salvage depths are determined by comparing soil analytical data to limiting chemical and physical criteria, and assigned to each unit based on this comparison. The area of each soil map unit is measured directly from the soils map, and the composition of the map units determined from the soil inventory. Available soil salvage volume is then calculated as the product of: 1) the area of the map unit; 2) the percent of each component comprising that map unit; and 3) the salvage depth, summed over all the components and all map units (see table 6-5). Salvageable soil volume estimates are then divided by the area to be reclaimed to get the average thickness of soil redressing.

This method, although easily accomplished, may not maximize salvage volumes. One reason is that the limiting criterion often is linked with an observable trait that can be described to the equipment operator (e.g., color). At the Navajo mine in northwestern New Mexico, for instance, an intensive soil analysis and mapping program conducted in 1973 resulted in topdressing material being mapped initially as 12 distinct groups of soils based on standard agronomic diagnostic criteria. Then soil color and texture (measured by feel) were shown to correlate highly with salinity, infiltration, and permeability, and the soils classification system was simplified to identify only those specific diagnostic properties that were directly related to what was known to be the most growth-limiting factor: effective moisture. By 1978, through continued analysis and observation of vegetative response, the original 12 groups of soils had been reduced to 3 (12).

A more quantitative methodology that weights limiting parameters may allow greater recovery of marginal soils in situations where soil volume is deficient, or maximization of soil quality where quantities are adequate (see box 6-L). This system is complicated and requires technical judgment for implementation. Moreover, unless the selection criteria and the weighting factors for the limiting parameters are well documented, use of the system may be subject to criticism during permitting.

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[18] Unless otherwise noted, the material in this section is adapted from reference 27.

Table 6-4.—Topsoil Unsuitability Criteria by State

Parameter	Montana (DSL 1983) (lift 2 only)	New Mexico (MMD 1984)	North Dakota (PSC, 1983) (lift 2 only)	Wyoming (DEQ 1984)
pH acid	<5.5	<6.0	none given	<5.0
pH alkaline	>8.5	>9.0	none given	>9.0
EC (mmhos/cm)	>4.0-8.0	>16.0	>4.0	>12.0
Texture	excessively clayey, silty or sandy	none given	none given	none given
$CaCO_3$%	none given	none given	none given	none given
Sat%	<25% >85%	none given	none given	none given
SAR	>11.0 >14.0 depending on texture	12.0 >15.0 >20.0 depending on texture	>10.0	15.0 >12.0 depending on texture
ESP	>15.0 >18.0 depending on texture	none given	none given	none given
B	>5.0 ppm	>5.0 ppm	none given	>5.0 ppm
Se	>0.1 ppm	>0.5 ppm	none given	>0.1 ppm
Coarse fragments (% volume)	>35%	none given	none given	>35%

SOURCE: James P. Walsh & Associates, "Soil and Overburden Management in Western Surface Coal Mine Reclamation," contractor report to OTA, August 1985.

As a further check on the reliability of the annual salvage volume estimates, some operators conduct an annual accounting of soil volumes. The volume of soils in stockpiles, the volume salvaged during the year and where it went (i.e., new stockpile, existing pile, or redressing), volumes redressed on reclaimed land and where it came from, and the volume remaining to be salvaged and the remaining area to be redressed, are calculated. This is referred to as the "soil budget," and provides a constant check on the reliability of presalvage estimates. Each year stripping depths are reevaluated and the salvage plan fine-tuned based on new data from ongoing salvage operations and on the results of monitoring the soil budget.

Salvage volumes usually can be estimated with sufficient accuracy for mine planning using the initial baseline data. However, due to the necessarily low density of sample sites in a baseline survey, it is possible to have a significant error. At one Montana mine, for example, the baseline soil survey delineated a foot of suitable topsoil in one area of approximately 1,000 acres (a small percentage of the total mine acreage). Subsequently the soil in this area was found to be suitable to only 4 inches due to a limiting chemical factor, representing a 67-percent reduction over the initial estimate.[19]

For actual salvage or annual volume calculations, more intensive soil-surveying methods are needed. For 5-year planning, the density of transects and sample points is increased to achieve better than 90-percent confidence in the predicted salvage volumes for that specific area. Annual planning is based on analysis of daily sampling and staking data to achieve better than 95-percent confidence in the volume estimates in order to maximize the efficiency of the soil stockpiling and replacement program and to avoid an unforeseen shortage and consequent expensive special handling. In fact, it is becoming increasingly common for a soil scientist to accompany equipment operators to ensure full recovery of the redressable soil material. Another approach is to leave soil pillars at roughly 200-foot intervals for inspection by agency and qualified mine personnel as a further check on the completeness of the salvage program.

There is a trend among larger mine operators to digitize soil inventory data and use computer

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[19] See case study mine D in reference 27.

Table 6-5.—Topsoil Volume Summary

Mapping unit symbol and name	Composition of mining area acres	Percent	Composition of mapping unit in % (should include inclusions)	Depth of topsoil (inches)	Total volume of topsoil (A-ft)	Average salvage volume of topsoil (A-ft)	Salvage depth of topsoil (inches)	Limitations[a]
1A Haverson loam	25.6	4.0	100	60+	128.0	50.7	28.0	SAR 15 at 28 in.
2B Bidman loam	76.8	12.0	90	50	345.0	345.0	50.0	
(Briggsdale sandy loam)			10	29	18.6	18.6	29.0	
44C Tassel-Shingle	44.8	7.0						
Rock outcrop			50	18	33.6	33.6	18.0	
complex								
Tassel								
Shingle			25	8	7.5	7.5	8.0	
Rock outcrop			25	0	0.0	0.0	0.0	
5A Stoneham loam	96.0	15.0	90	60	432.0	432.0	60.0	
(Cushman)			10	24	19.2	19.2	24.0	
78 Briggsdale	140.8	22.0	95	29	323.2	323.2	29.0	
sandy loam			5	12	7.0	7.0	12.0	
(Shingle)								
9A Ft. Collins-Ulm	70.4	11.0						
Association			50	60	176.0	176.0	60.0	
Ft. Collins Ulm			45	60	158.4	58.4	60.0	
(Shingle)			5	12	3.5	3.5	12.0	
6B Thedalund	108.8	17.0	100	24	217.6	217.6	24.0	
7B Cushman	76.8	12.0	100	24	153.6	153.6	24.0	
Total	640.0	100.0			2023.3	1951.9		

( ) indicates inclusion

Average depth of replacement

$$\frac{1951.9 \text{ A-ft}}{640 \text{ A}} = 3.0$$

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[a] Where topsoil salvage depth is different from the depth of topsoil, the limiting factor should be defined.

SOURCE: James P. Walsh & Associates, "Soil and Overburden Management in Western Surface Coal Mine Reclamation," contractor report to OTA, August 1985.

Box 6-L.—A Quantitative Technique for Determining Soil Suitability[1]

An innovative technique was used to evaluate soil suitability at one New Mexico mine. Several soil pedons were described, sampled, and analyzed for the standard set of parameters. A "soil-potential rating for topsoil" (see fig. 6-6), was developed from the data and pedon descriptions. A numerical rating was assigned to several chemical parameters and a rating was given for the whole soil and the limiting horizon on a horizon-thickness weighted average and summed. In this method the relationship between sodium adsorption ratio and clay was expressed as sodium adsorption ratio, times clay percent, divided by 10. The system has the advantage of simultaneously weighting several chemical and physical parameters rather than using individual unsuitability limits, and could be refined and used to maximize reclaimed soil quality at a site.

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[1] See case study mine M in reference 27.

Figure 6-6.—Example of a Weighted Topsoil Quality Evaluation

Numerical ratings of physical and chemical properties of soils to determine potential rating for use as "topsoil" in reclamation.

Soil parameters	Pedons		
	1-Muff	2-Youngston variant	3-Huerfano
	Index[a]		
Texture:			
Average	—	10	10
Limiting layer	10	10	20
% clay above 27	—	—	3
SAR x Clay/10:			
Average	61	34	135
Limiting layer	72	50	266
EC:			
Average	10	5	10
Limiting layer	10	10	10
Depth	30	—	60
$CaCO_3$:			
Average	—	—	—
Limiting layer	—	—	—
Coarse fragments:			
Average	—	—	—
Limiting layer	—	—	—
Boron	—	—	—
Total index rating	193	119	514

[a] Soils with lowest total are rated best for topsoil.

Suitability of soil as a source of topsoil.

Soil parameter	Soil rating (Index[b])		
	Good	Fair	Poor
Texture	SI, SIL, L (0)	SC, CL, SCL, SICL (10)	S, LS, C SIC (20)
Water at saturation (%)	>25	—	<25
pH	<8.4	8.4-8.9	>8.9
Sodium absorption ratio (SAR)	<6	6-15	<15
Electrical conductivity (EC)	<4 (0)	4-8 (5)	>8 (10)
Coarse fragments (%)	<15 (0)	15-35 (10)	>35 (20)
$CaCO_3$ (%)	<15 (0)	15-30 (10)	>30 (20)
Depth (in)	>40 (0)	20-40 (30)	<20 (60)
Boron (mg/1)	—	—	>4 (20)

[b] The numbers in parentheses are the index values used to develop the numerical ratings.

SOURCE: James P. Walsh & Associates, "Soil and Overburden Management in Western Surface Coal Mine Reclamation," contractor report to OTA, August 1985.

software to analyze the data and to update the estimates of available soil volumes on a daily or weekly basis. This level of sophistication is especially useful at mines with daily staking and sampling programs, where otherwise there would be some question about whether or not the data were being fully utilized.

The principal model for predicting the success of soil reclamation is an informal analysis of spoil quality and soil thickness. Research in the five States on production, cover, rooting depth, and plant quality as a function of soil thickness over spoil with various characteristics has been used to develop guidelines for factors that affect optimum soil thickness for revegetation. These factors are: vegetation type, soil and spoil quality, landscape position, and average annual precipitation. Table 6-6 summarizes some of the published research on soil thickness requirements, and illustrates the concept that soil depth must increase as spoil quality decreases. To evaluate proposed soil reconstruction plans, regulatory authorities use a qualitative analysis that compares predicted spoil characteristics, redressed soil quality, and average precipitation. The informal model illustrated in figure 6-7 was developed for evaluating reclamation plans in the high-desert Southwest. This model is useful because it allows formulation of site-specific recommendations for soil reconstruction, rather than blanket requirements for soil thickness.

Designing Hydrologic Reclamation[20]

In designing hydrologic and sediment control structures and restored surface drainage systems, it is necessary first to estimate the peak and low flows. As discussed previously, this can be accomplished with statistical methods if sufficient historical data are available; otherwise statistical or deterministic models are used. The USGS multiple regression equations (Log-Pearson Type III distribution method) are especially useful in predicting peak flood flows for sizing culverts and ditches at coal mines, and have officially been approved for this use by at least one State regulatory authority (Wyoming).

The numerous permit applications reviewed for this study revealed that many operators are using computers to calculate rainfall-runoff for use in the design of hydraulic structures. Programs in common use are: TR-20 (21), TRIHYDRO (30), and SEDIMOT II (32). Input and output from the TRIHYDRO model are illustrated in figure 6-8. The TR-20 model was used at one case study mine in North Dakota to quantify the loss of water storage and the resulting increase in area streamflow for wetlands that would not be restored after mining.[21] The program SEDIMOT II can be used to predict the runoff and sediment response of a watershed to a particular rainfall event. It is similar to the first two models, and is thus useful in the design of sediment control structures.

Where in-house computer capability is not available, deterministic modeling can be applied indirectly through the use of technical reports based on models. These reports enable users to obtain approximate runoff for a precipitation event using a family of curves developed for steep or mild slopes within a hydrologic region. One such report is used extensively by operators in Colorado to design sedimentation ponds and size culverts and ditches (22,23).

Deterministic rainfall-runoff models have several advantages over other methods of estimating peak flows and runoff volumes in the design of hydrologic control structures. They can be used to compare runoff from a given precipitation event for conditions before, during, and after mining. Also, because they utilize precipitation as a direct input they fulfill the common regulatory requirement for the determination of a runoff hydrograph for a designated precipitation event (e.g., the 10-year, 24-hour storm used for the design of sedimentation ponds). Finally, rainfall-runoff models can be used to compute a complete runoff hydrograph rather than merely a peak discharge and total runoff volume.

As noted previously, however, the results of deterministic models can be unreliable. Additionally, there appears to be no general consensus among regulatory personnel on a preferred method, and selection of a particular method depends on the capabilities or preferences of the individ-

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[20] Unless otherwise noted, material in this section is adapted from reference 30.

[21] See case study mine C in reference 30.

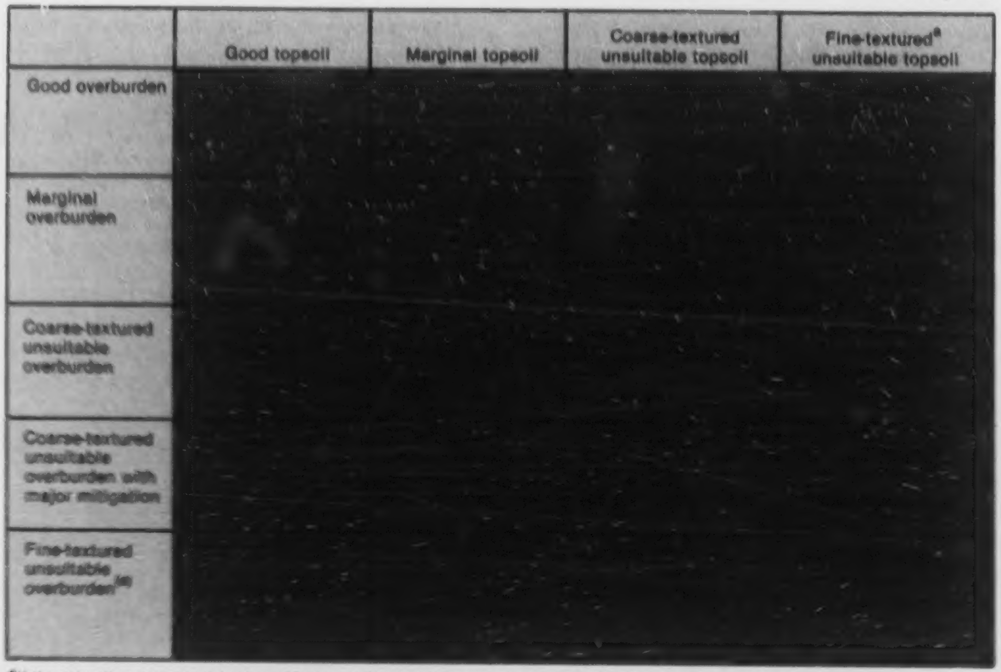
Table 6-6.—Summary of Some Topsoil Depth Research

Overburden quality	Topsoil quality	Land use or vegetation	Region	Optimal depth	Comments
No adverse properties, similar to soil	Nonsaline, nonsodic, loamy	Cool season grasses	Eastern Powder River Basin	No soil required	It appears that in some areas of the Northern Great Plains spoil is equal to soil in its ability to support plant production
—	—	Wheat	Colstrip MT	Greater than 4 in.	4 to 8 in. adequate
Slightly saline	—	Wheat grain	ND	6 in.	No higher yields on thicker topsoils
Good	—	Row crops	—	6 in. minimum	May not be significant in later years
Slightly sodic	—	Annual crops	ND	12 in.	—
Poor SAR = 20-30	Loamy 1:1 clays	—	Northern Great Plains	12 in.	May be adequate if the mine soils physical characteristic prevent upward salt migration
Orphan mine overburden	—	—	Southern WY	12-18 in.	"Satisfactory" cover not obtained unless 12 to 18 in.
NW Colorado overburden	—	Wheat; intermediate wheatgrass	—	18 in. (or more)	Yields increased from 0 to 18 in. optimum may have been greater
Slightly saline	Nonsaline, nonsodic, loamy	Cool season grasses	WY, MT, ND	20 in. optimal	Native plants require slightly more; optimal depth increases in wet years
Sodic	—	Wheat grain	ND	20-28 in.	Yields did not increase when thickness exceeded 20 to 28 in.
Medium EC < 6 SAR < 12	Good topsoil	—	ND	24-30 in.	Landscape position as important as depth; 12 in. topsoil over 12 to 18 in. subsoil
Slightly saline	—	Wheat, straw, corn	ND	25 in. or more	Increased with each application of soil thickness
Sodic SAR = 25 dispersed	Good topsoil slightly saline sodic subsoil	Crested wheat and native grass; alfalfa spring wheat	Central ND	28-36 in. optimal	Best results when topsoil was over subsoil; 8 in. topsoil over <8 in. subsoil
—	—	Native grass	WY	28-42 in.	Low precipitation regimes; 4 to 6 in. topsoil over 24 to 36 in. subsoil
—	—	—	—	Greater than 30-40 in.	Maximum production with thin soil layer
Sodic SAR 28 clayey	Nonsaline, nonsodic, loamy	Cool season grasses	MT and ND	32 in.	Annual and species variations can range from 26 to 37 in.
Coarse EC < 6, SAR < 12	Good topsoil	—	ND	36-42 in.	12 in. topsoil over 24 to 30 in. subsoil
SAR 12-20	Good topsoil	—	ND	36-48 in.	12 in. topsoil over 24 to 36 in. subsoil
—	—	Deep rooted crops	WY	40-46 in.	Higher precipitation regimes; 4 to 6 in. topsoil over 36 in. subsoil
SAR > 20	Good topsoil	—	ND	48-60 in.	12 in. topsoil over 36 to 48 in. subsoil
Strongly acid ph = 4.0	Nonsaline, nonsodic, loamy	Cool season grasses	WY, ND, MT	More than 60 in.	Maximum yields occur at depths greater than 60 in.

SOURCE: James P. Walsh & Associates, "Soil and Overburden Management in Western Surface Coal Mine Reclamation," contractor report to OTA, August 1985.

Figure 6-7.—Minesoil Construction in the High Desert Ecosystem in the Southwestern United States Where Limited Soil and Regolith Are Available for Salvage

January 1984



	Good topsoil	Marginal topsoil	Coarse-textured unsuitable topsoil	Fine-textured[a] unsuitable topsoil
Good overburden				
Marginal overburden				
Coarse-textured unsuitable overburden				
Coarse-textured unsuitable overburden with major mitigation				
Fine-textured unsuitable overburden[(a)]				

[a] If the saturation percentage is above 85 percent, the problems and attenuate risks will be even more severe.

SOURCE: James P. Walsh & Associates, "Soil and Overburden Management in Western Surface Coal Mine Reclamation," contractor report to OTA, August 1985.

ual performing the calculations. Conflicts do arise between the regulatory authority and the operator over the validity of the estimate, on which much of the surface water engineering design is based. To avoid these conflicts and the potential for expensive redesign, and to avoid the property damage and loss of life that could result from failure of a structure due to underdesign, most operators are intentionally conservative in their calculations.

Design of Hydrologic and Sedimentation Control Structures

Techniques for the design of hydrologic control structures and sediment control facilities have changed very little since promulgation of final rules and regulations under SMCRA. There is an increasing use of computers in design, and there has been a gradual standardization of runoff and sediment estimating techniques toward the SCS triangular hydrograph technique and the Universal Soil Loss Equation (USLE), respectively.[22]

Whether designing sediment ponds, or planning alternative sediment control measures, it is necessary to estimate the amount of sediment that will erode from a watershed and be subject to transport downstream during a precipitation event. Most operators use some form of the SCS triangular hydrograph technique to compute the 10-year 24-hour runoff volume, and some estimate of gross erosion, together with an appropriate sediment delivery ratio, to estimate sediment accumulation. In the absence of site-specific data (the usual case), the most widely accepted method for estimating gross erosion is the USLE. With limited available data for input, the strength of the method lies in its ability to provide rela-

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[22] Examples of application of the SCS triangular hydrograph and of the USLE can be found in case studies E, Q, S, and T in reference 30.

Figure 6-8.—Example of Input and Output for TRIHYDRO Rainfall-Runoff Model

SAMPLE INPUT SESSION:

```
ENTER TITLE FOR THIS STUDY
Sample Watershed, 10-YR 24-HR storm
Drainage area in square miles .................  ? 0.68
Watercourse length in miles ...................  ? 2.00
Elevation difference in feet ..................  ? 195.0
Curve number (CN) .............................  ? 75
Minimum infiltration rate (in/hr)..............  ? 0.24
Adjusted precipitation (inches)................  ? 2.99

ARE ALL VALUES OK? (Type N or carriage return)
```

INPUT OPTIONS

```
NOW YOU MUST SELECT A DESIGN PRECIPITATION
DISTRIBUTION. YOU MAY SELECT EITHER A DEFAULT
DISTRIBUTION OR INPUT YOUR OWN.

DEFAULT DISTRIBUTION SELECTIONS:
-1,-1.........USBR 6-HR General storm, Zone C,
              Extended to 10 hrs-use for PHP
-2,-2.........USBR 1-HR Thunderstorm, Zone III
-3,-3.........USBR 24-HR General Storm, Zone C
-4,-4 ........USBR 24-HR General storm, Zone B
-5,-5.........USBR 1-HR Thunderstorm, Zone II
-6,-6.........SCS TYPE II 24-HR General storm
-7,-7.........USBR 6-HR General storm, Zone B
-8,-8.........USBR 6-HR General storm, Zone C
-9,-9.........SCS TYPE II 6-HR General storm
-10,-10.......SCS TYPE I 24-HR General storm
-11,-11.......SCS TYPE I 6-HR General storm

Enter one of the above default distributions or type in a new
distribution. To type in a new distribution give the time in
hours and the percent of the precipitation that has fallen by
that time. Each pair of data (i.e., each time increment and per-
cent value) is followed by a carriage return. Both the time
increments and the percentage values must be in ascend-
ing order or an error will result. Percent values are given as
whole numbers (i.e., 10.4 = 10.4 percent). Terminate with 0,0
(carriage return)
-3,-3
```

SAMPLE SUMMARY OUTPUT

```
SAMPLE WATERSHED, 10-YR 24-HR STORM
BASIN CHARACTERISTICS:
   Drainage area (sq.mi.) ....................... =    0.680
   Stream length (mi) ........................... =    2.000
   Elevation difference (ft) .................... =  195.00
   Runoff curve number (CN) ..................... =   75.00
   Minimum infiltration loss (in/hr) ............ =    0.240
PRECIPITATION FOR SPECIFIED STORM:
   Adjusted precipitation for selected storm .... =    2.99
UNIT HYDROGRAPH PARAMETERS
   Unadjusted time of concentration (hr) ........ =    0.76
   Adjusted time of concentration (hr) .......... =    0.91
   Duration of excess rainfall, D (hr) .......... =    0.12
   Time to peak (hr) ............................ =    0.61
   Base time (hr) ............................... =    1.62
   QPEAK (peak flow in CFS for
      unit hydrograph) .......................... =  541.6
RESULTANT HYDROGRAPH VALUES
   Peak discharge (CFS) ......................... =   78.79
   Runoff volume (acre-feet) .................... =    7.36
   Time to peak discharge (hr) .................. =   10.41
USED: 24-HOUR GENERAL STORM, ZONE C
```

DESCRIPTION OF INPUT DATA VALUES

DRAINAGE AREA IN SQUARE MILES—Planimetered from the largest topographic map available.

STREAM LENGTH IN MILES—Length of longest watercourse from the point of interest to the watershed divide, measured from the best topographic map available.

ELEVATION DIFFERENCE IN FEET—Determined by subtracting the elevation at the point of interest from the elevation at the watershed divide where the stream length was determined, elevations taken from the best topographic map available.

CURVE NUMBER (CN)—Dimensionless index developed by the SCS to represent the combined hydrologic effect of soil, land use, agricultural land treatment class, hydrologic condition, and antecedent soil moisture. Taken from Hydrology, section 4, National Engineering Handbook, Soil Conservation Service (1972).

MINIMUM INFILTRATION RATE (in/hr)—Minimum infiltration rate for the soils in the drainage area. Estimated using Design of Small Dams, United States Bureau of Reclamation (1977).

ADJUSTED PRECIPITATION (inches)—The rainfall amount associated with desired recurrence interval. Estimated using NOAA Atlas 2, Precipitation-Frequency Atlas of the Western States.

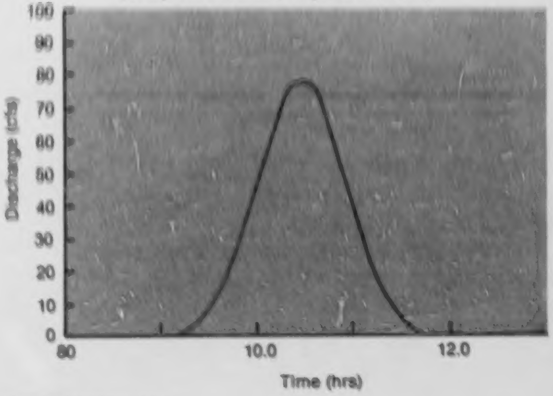
DESIGN PRECIPITATION DISTRIBUTION—Within-storm distribution of rainfall selected from 1 of the 11 distributions provided in the program or entered by the user.

OUTPUT OPTIONS

1. Summary Output (always provided)
2. Summary of Intermediate Calculations (optional)
3. Data Describing Individual Triangular Hydrographs for the Runoff Period Only (optional)
4. Tabulation of the Resultant Runoff Hydrograph (optional)

HYDROGRAPH EXAMPLE
(Plotted using the runoff hydrograph table output from TRIHYDRO)

RUNOFF HYDROGRAPH
(Sample watershed, 10-yr 24-hr storm)



SOURCE: Reference 29.

tive rather than absolute estimates for comparison of alternative projects.

Box 6-M.—Use of the SEDIMOT II Model[1]

A mine operator in Wyoming developed a design method using an industry-standard computer simulation model (SEDIMOT II) to design and substantiate both conventional and alternative sediment control practices in support of a permit application. SEDIMOT II simulates runoff from an area as well as the effectiveness of a variety of sediment control techniques, allowing the various techniques to be tested, without actual implementation, and the best sediment control technique can be chosen on a site-by-site basis. By using this design method, it is not necessary to have an actual runoff event in order to determine problem areas. The goal of this computer-assisted design procedure was to obtain computed water quality (suspended-sediment concentration), via alternate sediment control techniques, within the limits of the selected design standard (30,000 mg/l). Successive computer iterations were conducted and additional sediment controls added as necessary until the design TSS concentration is achieved (see also ch. 8, box 8-B).

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[1] See case study mine I in reference 30.

Design of sediment control structures requires calculation of the runoff response of the watershed to a specified precipitation event using one of the flood-estimating techniques discussed previously, and of the sediment yield, normally using the USLE. A computer program, SEDIMOT II, has been developed specifically for this purpose (see box 6-M); it allows rapid, accurate analysis in simulating larger areas in greater detail and over shorter time steps than is possible with hand calculations (32). In the example in box 6-M, an extensive monitoring program was instituted to determine the effectiveness of the various control techniques (see also ch. 8, box 8-B). The additional monitoring data also could be used to calibrate the model, since an initial data insufficiency did not allow calibration of the model to each of the separate drainages evaluated.

Design of Restored Surface Drainage Systems

Individual site characteristics will determine whether restoration of stream channels is a simple matter of reestablishing premining channel slopes, cross-sections and bed form, or whether a complete analysis of the pre- and postmining drainage basins must be undertaken to reconstruct an entire drainage system on the reclaimed surface (see ch. 3). Several approaches have been developed toward restoration of the surface drainage system. Selection of the approach depends on the experience and preference of the operator (or permit applicant), the desires of the regulatory personnel reviewing the application, and the site characteristics. In the permit applications examined for this assessment, OTA found that the amount of detail in the designs of reclaimed surface water drainage systems ranged from almost none to very elaborate designs based on geomorphic and hydraulic studies (see box 6-N).

Box 6-N.—Surface Drainage System Design[1]

At a mine in North Dakota, a surface drainage system was to be restored in an area of relatively steep slopes. A quantitative analysis of the premining drainage basin included a topographic map on which basins and channels were located, and a determination of the various geomorphic parameters of the premining drainage basin. However, the operator apparently made little use of these data in designing the postmining drainage system. The permit application did not discuss the analytical techniques used to design the restored system. The application did include a postmining topographic map indicating the location of postmining channels, along with a comparison between longitudinal profiles of the restored channels and premining profiles. In the comparison, the postmining channels had steeper, more variable slopes and a lack of upward concavity compared to the premining channels. There were no postmining drainage basin characteristics, no design flood flows, and no hydraulic designs of channels and flood plains in the permit application.

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[1] See case study mine A in reference 30.

In the simplest case, where mining only removes a portion of a channel, the reclaimed segment design is made by direct field measurement of channel cross sections and profiles, and then duplication of the undisturbed channel cross section, longitudinal profile, and sinuosity. If the channel is alluvial, data are required on bed-material size and gradation to assure maintainance of adequate sediment transport rates and channel stability.

The advent of computers, especially personal computers, and readily available software for applications such as rainfall-runoff computations and water surface profile calculations, have added to the operator's abilities to prepare and analyze site-specific channel properties. This increases the assurance that well-designed, restored drainage systems will be erosionally stable. Design is aided by the use of computerized water-surface profile analysis programs (e.g., HEC-2, developed by the U.S. Army Corps of Engineers). Predicted velocities from successive postmining channel designs are compared to those found under undisturbed conditions until a channel geometry is found that meets all of the design goals. Data requirements for this type of hydraulic analysis are not extensive, and include only the data from the field survey of the channel and those data necessary to compute or select design-discharge levels and cross-sections and profiles.

Mines that cover large areas or contain relatively small watersheds often must reconstruct entire drainage basins. Where the overburden to coal ratio is very large or very small, the postmining drainage basin characteristics may differ substantially from the premining characteristics, further complicating the design problem (see ch. 3). Many operators base their reclamation plan in part on a quantitative geomorphologic analysis of the premining drainage system, and attempt to apply relationships determined from this analysis to the design of the restored system. Hydrologists and engineers work together to create a new "steady state" by manipulating the surface, slope, and channel configuration so that the newly formed system will be approximately in equilibrium with respect to erosion and sediment transportation processes. The most important design parameters are channel longitudinal profiles, drainage density, and channel and floodplain cross-sectional geometry.

Review of mine plans has revealed an encouraging trend toward a comprehensive, multidisciplinary approach to the design of restored surface drainage systems. Operators are combining the concepts of quantitative geomorphology with rainfall-runoff hydrology and detailed hydraulic analyses to develop plans for the restoration of erosionally stable channels and watersheds. The importance of this aspect of reclamation is becoming increasingly apparent as reclamation proceeds and problems in channel stability are beginning to appear at some mines. Considering that the performance bond evaluation period is relatively short in comparison to the frequency of design flow events for restored surface drainages, it would be difficult to judge the success of surface drainage restoration within the bond release period. Evaluation of drainage restoration will have to be based to a large extent on the design in the reclamation plan, which underscores the importance of the correct application of the analytical techniques that produce that design.

Design and Reclamation of Alluvial Valley Floors[23]

In general, the analytical procedures for AVFs are similar to those used in non-AVF areas, but are applied more intensively. In AVF areas, monitoring and data collection are more concentrated spatially and temporally, and the results are reviewed more rigorously by regulatory authorities due to statutory protections for AVFs. Hydrologic studies of AVF areas are unique in that, by law, they are required to analyze the relationships between hydrologic conditions in surface and groundwaters and in land use, soil characteristics and vegetative productivity. In addition, most mine permit applications provide a thorough assessment of the geomorphic and erosional characteristics of the valley floor, if it is to be physically disturbed. To assess the special relationships in AVF areas, most permit applications attempt to quantify the variables of the hydrologic budget of the valley floor.

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[23] Unless otherwise indicated, the material in this section is adapted from reference 30.

Analytical techniques used to predict the impacts of mining on AVFs and to demonstrate that the essential hydrologic functions will be restored are similar to those previously described for surface and groundwater investigations. Special functions of AVFs that must be determined premining include the interchange of water between the surface stream and the alluvial aquifer and between the alluvial aquifer and bedrock aquifers; the depth to the alluvial water table and the soil texture above the water table; and water quality in the stream and alluvium. In planning for the restoration of AVFs, attention is focused on channel and floodplain geometry and erosional stability, and alluvial aquifer depth, thickness, and water-storing and transmitting capabilities (transmissivity and storage coefficient).

At a mine in Wyoming, potential alluvial drawdowns were predicted using a well-field simulation model.[24] Use of this model required assumptions of the alluviated valley width, aquifer-specific yield, and dewatered aquifer length. The volume of water extracted in the dewatered alluvium was compared to flood flows in the intermittent channel. This evaluation indicated that "any moderate-sized flood event would totally recharge the dewatered material." The postmining monitoring program includes detailed plans to support this contention.

The criteria for premining evaluation of the essential hydrologic functions of AVFs are generally standardized among the regulatory agencies of the Western States. These same criteria are also applied, postmining, in evaluating the success of AVF reclamation (see ch. 7). The criteria are based on accepted engineering and hydrogeologic principles, and the probable success of reclaiming AVFs generally is viewed with confidence. As with hydrologic restoration in non-AVF areas, however, in some instances it may be many years or decades until reclamation success in AVF areas can be finally assessed.

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[24] See case study mine J in reference 30.

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Chapter 7

Standards and Methods for Evaluating the Success of Reclamation

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Chapter 7

Standards and Methods for Evaluating the Success of Reclamation

CHAPTER OVERVIEW

Few aspects of the process for evaluating the success of reclamation have been firmly established under the Federal and State regulatory programs, leaving many uncertainties and issues. None of the five States examined during this assessment has established bond release criteria for Phases II and III. Most existing evaluation techniques and standards which the States could draw on to develop Phase II and III criteria have serious limitations. These limitations are particularly problematic in revegetation and hydrology—the two areas emphasized in the Surface Mining Control and Reclamation Act (SMCRA) performance standards.

To date, no method for evaluating revegetation adequately addresses both changes over time and spatial diversity over a large area. There is general agreement that revegetation standards should accommodate the climatic and temporal variations that affect all aspects of vegetation. However, the most widespread method for doing this—reference areas—assumes that vegetation on a few acres will vary in the same manner as, and thus can adequately represent, vegetation over thousands of acres.

Evaluation of hydrologic restoration is even more unclear. Although the SMCRA performance standards emphasize hydrology, most reclamation evaluations have focused on revegetation success. As a result, **neither operators nor regulatory authorities have much experience with applying hydrologic success standards, and the few standards currently in place are of questionable practicality.** The greatest uncertainties in evaluation of hydrologic restoration are insurmountable, and will simply have to be recognized in the evaluation process. The hundreds of years predicted to be necessary for resaturation of many spoils-aquifers in the West make it impractical to actually measure spoils water quality. Therefore, evaluations will have to be made with incomplete knowledge and available predictive tools. Similarly, some reconstructed surface drainage systems are unlikely to experience peak flow events during the liability period, and predictive techniques and design criteria must be used to evaluate these drainages.

There also is uncertainty about whether successful revegetation and hydrologic restoration are sufficiently reliable indicators of success for soils, overburden, and wildlife. Of particular concern is the time factor involved in spoils oxidation and the potential for deleterious overburden material to cause problems in the root zone after regraded spoils sampling.

Legal questions about liability under the mix of performance and design standards currently used by regulatory authorities are unresolved. If regulatory authorities require a certain reclamation design, and that design fails, are operators still liable for repairing the reclamation failure? A recent slump in Colorado (see below) raises this question.

In addition, there are practical questions about the relative effectiveness of performance and design standards. Performance standards better encourage innovation and selection of the most cost-effective reclamation methods. However, they also have a greater potential for reclamation failure if innovation is not conducted responsibly and if monitoring data are not routinely used to track and modify new practices. On the other hand, while design standards seem to provide greater protection against failures and operator irresponsibility, they can stifle innovation and may not ensure achievement of the desired performance.

PERFORMANCE BONDS AND THE BOND RELEASE PROCESS

SMCRA requires that surface mined lands be restored to a condition capable of supporting the premining land uses or to higher or better uses (24). All of the data collection and analysis conducted by operators and regulators described in the preceding chapters is directed toward meeting this requirement. This chapter examines the criteria and methods used to judge the success of reclamation efforts.

The Federal regulations define "reclamation" as "those actions taken to restore mined land as required by this chapter to a postmining land use approved by the regulatory authority"(17). The basic reclamation requirements in the Federal regulations provide only a general outline of reclamation performance standards, however; they can rarely be applied without substantial interpretation and refinement by State regulatory authorities. This fits with the intent of SMCRA, that the primary governmental responsibility for regulating surface mining and reclamation should rest with the States (see ch. 4) (23).

In order to receive a surface mining permit under SMCRA, operators must put up a performance bond. A bond may either cover an entire permit area or may be filed in increments as the mine progresses. The amount of the bond is set by the regulatory authority and must be sufficient to pay for completion of the reclamation plan in the event of forfeiture. For the very large surface mines prevalent in the West, this usually means bonds of millions of dollars.

In practice, evaluation of reclamation success has become virtually synonymous with bond release. Therefore, the procedures for bond release outlined in SMCRA have shaped the way reclamation success is evaluated. Instead of keeping the entire bond until reclamation has been judged a complete success, which would be financially burdensome for an operator, the Act provides for a phased release of the bond in portions that reflect the operator's reclamation costs (25). The phases of bond release described in SMCRA are:

- *Phase I:* When an operator completes the backfilling, regrading, and drainage control of a bonded area in accordance with the approved reclamation plan, he may apply for the release of up to 60 percent of the bond for that area. Topsoiling may be required for the release of this phase, at the regulatory authority's discretion.
- *Phase II:* A second portion of the bond may be released after vegetation has been established on the regraded mined lands and those lands are not contributing suspended solids to streamflow or runoff outside of the permit area in excess of the regulatory requirements. The amount of this second release usually is 15 to 25 percent. The precise amount is left to the discretion of the State regulatory authority, which must retain a sufficient amount of the bond to cover the cost of hiring a third party to reestablish vegetation should the operator forfeit.
- *Phase III:* The remaining bond monies are released only after the operator has successfully completed all surface coal mining and reclamation activities in accordance with regulatory requirements and with his permit. SMCRA specifies that, in areas where the average annual precipitation is less than 26 inches (virtually all of the study area), the operator must assume responsibility and liability for successful revegetation for 10 years after the last year of augmented seeding, fertilizing, irrigating, or other work. Final success evaluation and final bond release cannot occur until this liability period has elapsed.

To date, none of the five State regulatory authorities has formulated criteria for all phases of bond release. Moreover, because permitting and bonding under SMCRA only began in the West in 1979 and 1980, very few operators are sufficiently advanced in their reclamation activities to apply for any type of bond release. There have been a few Phase I releases (discussed further below), but no Phase II or final releases of any bonds posted under SMCRA. In the next few years, however, more and more operators will be filing for release of various portions of their bonds. Regulatory authorities will then have to decide whether they need to develop more specific criteria for evaluating reclamation. Preliminary indications are that criteria will differ significantly among the States, depending on environmental and mining conditions and regulatory philosophies.

The State regulatory authorities are drawing up standards for judging reclamation as those standards are needed. By waiting until applications for bond release are submitted, the regulatory authorities hope to incorporate more of the reclamation experience they are rapidly gaining into their criteria and evaluations. This means, however, that operators must proceed on the assumption that bond release criteria will be the same as the revegetation and other performance and design standards in SMCRA and the regulatory programs. **Regulators' flexibility to establish more detailed criteria may be limited by approved reclamation plans that establish de facto criteria on a case-by-case basis.**

STANDARDS AND METHODS USED TO JUDGE RECLAMATION SUCCESS

Without approved bond release criteria for reclamation parameters beyond Phase I backfilling and grading, and without any examples of Phase II or Phase III bond release, a definitive assessment of the bond release process cannot be undertaken. A preliminary assessment of the methods for evaluating reclamation success can be made, however, based on the Federal and State performance standards.

It is reasonable to assume that specific criteria for reclamation success will be based on the performance standards, and that the methods used to evaluate reclamation will be similar to those developed by technical specialists in the various reclamation disciplines for use in research and in the development of mining and reclamation plans. This section reviews the types of reclamation standards and success evaluation methods available, their advantages and disadvantages, and their use by the different State regulatory authorities. The following section describes the States' experience to date in applying these standards to actual bond release situations.

Types of Standards: Performance vs. Design

There are two broad categories of success standards—performance standards and design standards. Performance standards describe the features that must be present for reclamation to be considered a success and allow the operator to choose a means of achieving this success. Design standards dictate specific aspects or methods of mining and reclamation which, in the regulatory authority's view, must be used to avoid adverse health and safety or environmental impacts. A requirement that discharges of total suspended solids (TSS) from a mine site not exceed natural premining levels is a performance standard. Requiring TSS to be controlled with sediment ponds of a particular capacity built at specified points on the site constitutes a design standard.

SMCRA incorporates both performance and design standards. The latter generally are used either for dams and other engineered structures whose failure would pose a significant threat to public safety and the environment, or when the regulatory authorities' professional staff believe that a required level of performance can only be achieved with a particular design. Evaluation of compliance with design standards is simpler, because it is a straightforward engineering assessment of whether the design has been executed properly. However, reliance on design standards carries with it the risk, albeit small in most cases, that the mitigation designs specified by the regulatory authority might not prove adequate in all cases.

Federal and State Standards

Section 515 of SMCRA contains minimum general performance standards from which more specific success standards are being formulated and implemented by the States (see ch. 4). Table

7-1 lists the most important of these performance standards for Western reclamation. As the table indicates, SMCRA requires:

- restoration of the land's approximate original contour (AOC);[1]
- stabilization of the surface against erosion;
- salvage and protection of topsoil, with special requirements for prime farmlands;
- minimization of disturbance to the hydrologic balance, including maintenance of water quality, restoration of the essential hydrologic functions of alluvial valley floors (AVFs), and restoration of aquifer recharge capacity;
- protecting revegetation and postmining water quality from acid-, alkaline- and toxic-forming overburden;
- establishment of a diverse, effective, and permanent vegetative cover of the same seasonal variety native to the area and capable of plant succession and regeneration; and
- assumption of responsibility for successful revegetation for a period of 10 years after completion of work on the area.

The Federal regulations interpret and supplement these legislative requirements (see ch. 4). Many of the Federal regulations simply restate requirements in SMCRA. Additional performance and design standards in the regulations address: immediate topsoil replacement; design of hydrologic control structures; protection of wildlife, including threatened and endangered species; and slope stability.

Performance and design standards developed by the States must be at least as stringent as the Federal standards. In the Western States, they often are more stringent. In addition, the standards and criteria developed by State regulatory authorities have to fill in a number of gaps in the Federal regulations, which deliberately leave some important success evaluation decisions up to the States, particularly the revegetation standards.

Table 7-1.—Selected Performance Requirements and Standards in SMCRA

General: Restore the land affected to a condition capable of supporting the uses which it was capable of supporting prior to any mining, or higher or better uses of which there is reasonable likelihood.

AOC: Grade to approximate original contour (AOC) so that all highwalls, spoil piles, and depressions are eliminated (unless small depressions are needed in order to retain moisture to assist revegetation or as otherwise authorized.

Erosion: Stabilize and protect all surface areas and effectively control erosion and attendant air and water pollution.

Topsoil: Remove topsoil in a separate layer, replace it on a backfill area, or if not utilized immediately, segregate it in a separate pile from other spoil and maintain a successful cover by quick-growing plants or other means so that the topsoil is preserved from erosion and protected from contamination by acid or toxic material. (If topsoil is of insufficient quantity or of poor quality for sustaining vegetation, or if other strata can be shown to be more suitable for vegetation requirements, then the operator shall remove, segregate, and preserve in like manner such other strata best able to support vegetation.

Prime farmlands: For all prime farmlands, remove, segregate, and preserve the A soil horizon separately from the B and C horizons and replace the A horizon on top of the B and C horizons.

Hydrology: Minimize the disturbances to the prevailing hydrologic balance at the mine-site and in associated offsite areas and to the quality and quantity of water in surface and groundwater systems both during and after surface coal mining operations and during reclamation.

Acid or toxic drainage: Avoid acid or other toxic mine drainage by such measures as, but not limited to:

1. preventing or removing water from contact with toxic producing deposits;
2. treating drainage to reduce toxic content which adversely affects downstream water upon being released to water courses;
3. casing, sealing, or otherwise managing boreholes, shafts, and wells and keep acid or other toxic drainage from entering ground and surface waters.

Surface water quality: Prevent as far as possible additional contributions of suspended solid to streamflow, or runoff outside the permit area. In no event shall contributions be in excess of requirements set by applicable State or Federal law. Siltation structures may be constructed for this purpose but they must be cleaned out and removed after areas are revegetated.

Aquifer recharge: Restore recharge capacity of the mine area to approximate premining conditions.

AVFs: Preserve throughout mining and reclamation the essential hydrologic functions of alluvial floors in the arid and semiarid areas of the country.

Revegetation: Establish on the regraded areas and on all lands affected, a diverse, effective, and permanent vegetative cover of the same seasonal variety native to the area of land to be affected and capable of self-regeneration and plant succession at least equal in extent of cover to the natural vegetation of the area; except, that introduced species may be used in the revegetation process where desirable and necessary to achieve the approved postmining land use plan.

Assume responsibility for successful revegetation for a period of 10 full years after the last year of augmented seeding, fertilizing, irrigation, or other work in areas where the annual average precipitation is 26 inches or less (5 years where annual precipitation is greater than 26 inches).

SOURCE: 30 CFR Part 800.

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[1] The act allows exceptions to this requirement for mines where it may not be compatible with the postmining land use, and for those with thin or thick overburden.

The Federal and State standards emphasize revegetation and hydrologic restoration for several reasons. First, the standards are based on an assumption that success in these aspects of reclamation will provide indirect measurements of success in other areas. Successful revegetation can only be achieved if there is sufficient quantity and quality of soil material. Wildlife habitat will be reestablished if adequate revegetation is achieved and water quantity and quality are restored. Maintenance of acceptable water quality, particularly dissolved and suspended solids levels, indicates that the land surface has been stabilized and that erosion will not be a problem. Second, vegetation and surface water are the most accessible reclamation parameters, and therefore the easiest to measure. Third, in most cases, these are the parameters that most directly affect achievement of the postmining land use.

Revegetation Standards[2]

Because of the emphasis on revegetation success—both historically and in SMCRA—the Federal regulations include much more specific standards for revegetation than for other aspects of reclamation. In particular, the regulations require:

- use of statistically valid sampling techniques for measuring revegetation success, which must include criteria representative of unmined lands in the area;
- evaluation of revegetation cover and production by approved methods, such that these parameters are not less than 90 percent of the success standard;
- use of tree and shrub stocking and vegetative cover standards for evaluation of success on lands whose postmining land use is wildlife habitat; and
- achievement of the relevant vegetative success standard for at least the last 2 years of the 10-year responsibility period, without augmentation practices not expected to continue as part of the postmining land use.

State and Federal revegetation performance standards vary with land use (see table 7-2). For each use they must define: 1) what vegetation characteristics, such as cover, production, woody plant density and diversity, are to be evaluated; 2) what vegetation standard, such as a reference area or an historical data standard, is to be used to evaluate reclaimed areas; and 3) what level of statistical comparability must be established between the reclaimed area and the standard, such as considering cover equal if it is at least 90 percent of the standard with 90 percent statistical confidence.[3]

Most of the lands overlying strippable coal in the five-State region are native rangelands—lands that support predominantly native vegetation used to graze domestic livestock. Most of these lands also support a variety of wildlife and therefore are considered to be wildlife habitat as well. North Dakota is an exception in the study area because cropland and tame pastureland have replaced most natural habitats. Vegetation parameters usually considered in judging reclamation success on native rangelands are cover, production, diversity, and woody plant density. Other land uses, such as mown pasture and row cropland, are evaluated with some subset of these parameters. Methods used to collect data on these vegetation parameters, from which evaluations can be made, are discussed in chapter 5.

The permanence of revegetation is explicitly evaluated only in Montana.[4] In Montana, permanence is considered to have been achieved if the revegetated area is composed of at least 51 percent native species, based on production and canopy cover. This standard assumes that native communities are more likely to be self-sustaining than introduced species, which is generally true.

Revegetation evaluations emphasize these parameters because of their relevance to the postmining land use. Vegetative cover is an indicator of the stability of the soil resource. Permanence and net above-ground annual production are measures of the utility of the vegetation for livestock grazing and for wildlife. Vegetative diversity generally is considered to be a measure of

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[2] Unless otherwise noted, material in this section is adapted from references 6 and 13.

[3] Many statistical standards of comparability were eliminated in the 1984 revisions to the Federal regulations, in effect making them standards of 100 percent with 100 percent confidence; see table 7-2.

[4] Use of a 10-year liability period addresses permanence indirectly, but it is not clear that this alone assures permanent revegetation.

Table 7-2.—Revegetation Performance Standards by Land Use Category and State

[illegible]	Colorado	Montana	New Mexico	North Dakota	Wyoming
[illegible]	Cover and production same as PRP rangeland. Woody plant density same as PRP (see PRP wildlife). Diversity same as PRP wildlife.	Cover and production with same statistical measures as PRP rangeland, but comparison is to weighted cover and productivity (see text). Woody plant density same as PRP wildlife. Weighted diversity (see text) with same statistics as diversity in PRP rangeland. Permanence if 51% cover and production are native species.	Cover and production same as PRP. Woody plant density same as PRP (see PRP wildlife). Diversity same as PRP wildlife.	Cover and production same as PRP rangeland. Diversity same as PRP rangeland.	Cover and production same as PRP rangeland. Diversity same as PRP rangeland.
[illegible]	Same as CO native rangeland.	Same as MT native rangeland.	Same as PRP wildlife.	Same as PRP wildlife. Trees same as stocking of PRP wildlife.	Same as WY native rangeland. Shrub density same as woody plant stocking in PRP wildlife.
[illegible]	Same as PRP cropland.	Same as PRP cropland.	Same as PRP cropland.	Same as PRP cropland.	Same as PRP cropland.
[illegible]	Same as PRP cropland.	Same as PRP cropland.	Not applicable.	Cover and production same as ND and PRP rangeland.	Same as PRP cropland.
[illegible]	Reference area or technical standard.	Reference area.	Reference area, technical standard, or historical record.	Reference area or other standard. A technical standard has also been accepted.	Reference area or control area.

NOTE: [illegible] for a State is stricter than the Federal PRP is it entered in the table. Stocking has the same meaning as density.
PRP [illegible] Regulatory Program.

SOURCE: [illegible], from Federal and State regulatory programs.

ecological stability and an indicator of the land's capability for supporting wildlife. Woody plants contribute to habitat diversity, providing forage and reproduction sites, protective cover, and physical and spatial heterogeneity in the habitat. Therefore, woody plant diversity and density are considered a measure of reclamation success where wildlife habitat is a postmining land use.

Success standards for these vegetation parameters are set by different methods. Cover and production usually are judged according to standards that attempt to adjust for the climatic variations which affect these parameters. Woody plant density and species/lifeform diversity standards are usually compared with quantitative goals called technical standards. These are negotiated between the operator and the regulatory authority based on the postmining land use, premining conditions, and practical constraints.

Five different systems of revegetation standards have been developed that meet the Federal requirement for inclusion of criteria based on similar unmined lands (22). Each system has advantages and limitations that determine its usefulness for the different climatic regions of the West and for the different vegetative characteristics to be measured. **The primary limitation, common to all of the systems, is their inability to address both the temporal variations in environmental conditions and the spatial diversity that occurs over large areas. An additional concern is the lack of testing under actual land use conditions.** For example, although the predominant land use in the study area is native rangeland, little test grazing has occurred on revegetated areas. Of the five States, only Montana has established guidelines for test grazing plans and monitoring data collection.

Unadjusted Baseline.—This system uses the quantitative values for cover and production observed during the baseline vegetation study (see ch. 5) as the revegetation standard. Thus, there is no adjustment for natural variability due to environmental change. Rather, the unadjusted baseline method implicitly assumes that year-to-year fluctuations in the measured parameters are negligible. This approach has not been used widely except at existing (pre-SMCRA) small mines that do not have enough land for reference areas.

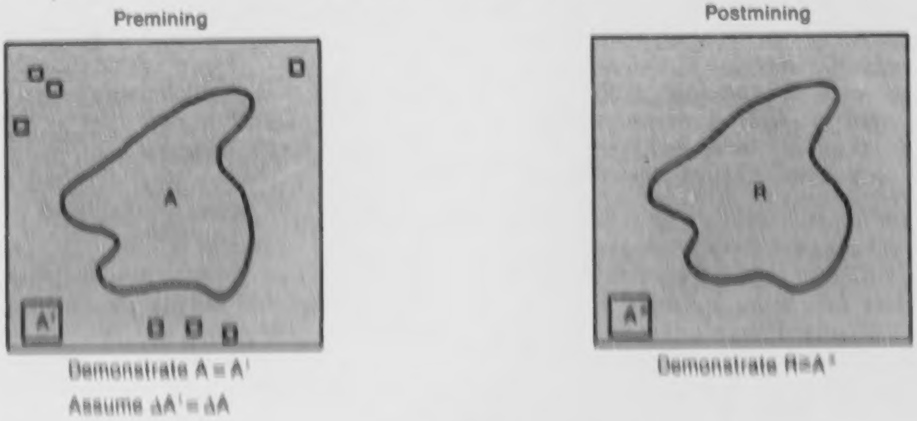
Photo credit: Jenifer Robison, OTA staff

Test grazing may be conducted on native rangeland or pastureland at some mines for the last 2 years of the liability period in order to assess the success of revegetation under actual land use conditions.

Reference Areas.—This method uses 2- to 3-acre plots of land, whose management can be controlled by the operator. The plots are chosen to be representative of one or more vegetation parameters (usually cover and production) on undisturbed lands similar to the area being reclaimed. The measured vegetation parameters on the reference areas constitute the success standard. The underlying assumptions of this method are that vegetative cover and production on the disturbed area should be equivalent to that on the reference area, and that the equivalency will hold over time and climatic variation. Vegetation on reclaimed areas is compared directly with the vegetation on the reference area at the close of the liability period. Baseline data are used only to establish comparability between the area to be disturbed and the reference area(s) during the baseline year. A premining demonstration of statistical equivalency between the reference area(s) and the proposed mining area is required (see fig. 7-1).

Operators must then demonstrate that cover and production of the reclaimed vegetation equals a prescribed percentage of the values in the reference area (often 90 or 100 percent) with a prescribed statistical level of confidence (usually 80 or 90 percent). The State regulatory au-

Figure 7-1.—Reference Area



A = area to be mined of vegetation type A.
A' = reference area whose vegetation is representative of area A in baseline year.
R = area revegetated in vegetation type A.
A'' = reference area in test year.

— Purpose of collecting baseline data is to demonstrate similarity of A and A'.

— Success standards are the values in A''.

SOURCE: Modified from G.P. Kunkel and E.J. Hinzel, "Considerations in the Application of Standards for Revegetation Success," in E. Redente, et al., *Symposium on Western Coal Mining Regulatory Issues: Land Use, Revegetation, & Management*, Colorado State University Range Science Department, Science Series No. 35, August 1983, pp. 31-35.

thorities prescribe levels of equivalence and statistical confidence, which may vary with land use or vegetation type. Reference areas are commonly used in all of the States except Wyoming.

Performance standards based on reference areas have the advantage of incorporating variations in vegetation due to climatic conditions. Reference areas also have a number of limitations, however. Most important is the underlying assumption that vegetation on a 2- to 3-acre plot can adequately represent the vegetation on an area many times larger (up to thousands of acres). Detailed ecological studies repeatedly demonstrate that vegetation is a mosaic of plant communities resulting from minor differences in the physical environment, localized population cycles of small mammals and insects, the natural growth and succession of individual plants and plant populations, and the cumulative effects of land use changes. Because cover and production also vary within this mosaic, a quantitative equivalency between a vegetation type on a reference area and a reclaimed area often is difficult or impossible to establish (see box 7-A).

Contro Areas.—Like reference areas, control areas are hosen to be representative of vegetation on an undisturbed area similar to the area being reclaimed. However, control areas are used differently to evaluate success. Vegetation parameters measured in control areas are not compared directly to the parameters on revegetated areas. Instead, vegetation samples from the control reference area in the test year are compared to values in the baseline year. The ratio of the test and baseline year samples is used to adjust the baseline data from the disturbed area for environmental and climatic changes over time. The adjusted baseline data are then used as the performance standard. Success is determined through a statistical comparison of the actual values in the

Box 7-A.—Use of Reference Areas

Extremely continental climates with erratic weather patterns, which are common in most parts of the West, make application of revegetation evaluation standards particularly difficult. Recent monitoring of revegetated grassland at a mine in east-central Montana illustrates the limitation on the use of small reference areas that results from variable vegetation response to changes in the distribution and amount of precipitation. One area of the monitored tract experienced a very dry winter and early spring, but more adequate late summer rain. Cool-season grasses therefore did poorly, but warm-season grasses did well. The result was a shift in apparent species composition in the area. In addition, production varied across the area according to the amount of warm-season grass in each community. Production on other areas of the tract, which experienced different rainfall patterns, varied not just by a few percent, but by as much as several orders of magnitude (6).

revegetated area and the adjusted baseline values (see fig. 7-2). Control areas are the preferred evaluation method in Wyoming.

Control areas share with reference areas both the advantage of incorporating variations in vegetation due to climatic conditions, and the disadvantage of assuming that the vegetation on a small control area can adequately represent the vegetation on a much larger area. The control area system, however, uses the control data only to formulate an adjustment factor for tract-wide baseline data. Therefore, it is somewhat less dependent on that assumption than the reference area method. But, it still assumes that vegetational response to climatic variation between the baseline and test years on the control area will be the same as the average across a vastly larger tract.

Control and reference areas also may be difficult to establish or maintain. Operators may not have land sufficiently similar to the mined land to set aside as reference or control areas. The small plots of vegetation can easily be disturbed or destroyed by changes in the mine plan, or by fire, insect infestation, and plant disease.

Historical Record.—Another method for addressing the temporal variations in vegetation parameters is to collect baseline data over a period considered to be one climatic cycle. Theoretically, this should bracket the potential variability in cover and production. In New Mexico, the only State in which the historical record approach has been used to a substantial extent, one climatic cycle typically has been regarded, albeit debatably, as at least 7 years.

Historical record data may be particularly useful for mines that will eventually disturb all lands suitable for use as reference areas; for areas where several mines are located in the same region and so can share the cost of collecting data to establish the historical record, as is the case in northeastern New Mexico; and for measuring production where the postmining land use is cropland. Use of an historical record avoids many of the problems associated with reference areas: site selection, measure of similarity, and management conflicts. It could accurately reflect the natural range of temporal variation in vegetation by incorporating samples over a much longer period of time. The limitation of this standard, however, is that the amount of data which must be collected in order to establish the record and the amount of time required to do this are both very large. Similarly, the most accurate evaluation method using the historical record requires a long period and a lot of sampling. For these reasons, it is not widely used outside of New Mexico.[5]

Moreover, it is not clear exactly how the accumulated data can best be used to judge revegetation success. One method developed jointly by the New Mexico Mining and Minerals Division (MMD) and the Office of Surface Mining (OSM) is to use the arithmetic mean of the historical record data as a technical guide with no associated variance term. With this approach, however, adequate revegetation could fail to meet the standards if it were evaluated in a drought year, and inadequate revegetation could be approved as successful if evaluated in a wet year. Another possible method would be to mon-

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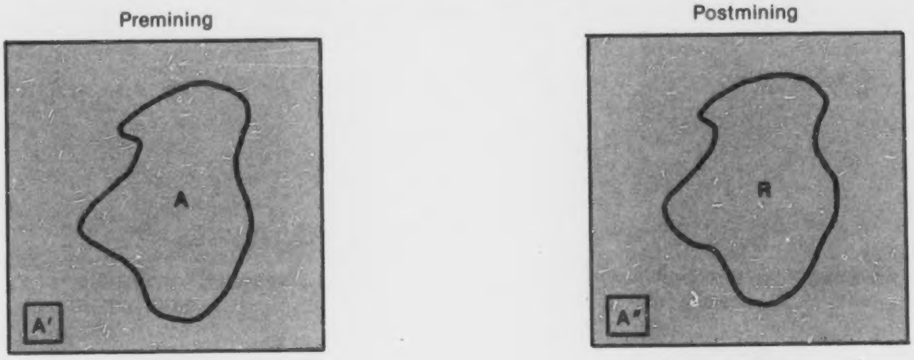
[5] For more information on use of the historical record standard in New Mexico, see reference 15.

Figure 7-2.—Control Area



Demonstrate $A \approx A'$

Assume $\Delta A \alpha \Delta A'$

Demonstrate $\frac{R}{A} \geq \frac{A''}{A'}$

$R \geq A'' \cdot \frac{A}{A'}$

A = area to be mined of vegetation type A.
A′ = control area whose vegetation is representative of area A in baseline year.
R = area revegetated in vegetation type A.
A″ = control area in test year.

— Premining data are used to establish quantitative relationship between the control area and the disturbed area.

— Success standards are the baseline vegetation values for A adjusted by relationship between A′ and A″.

SOURCE: Modified from G.P. Kunkel and E.J. Hinzel, "Considerations in the Application of Standards for Revegetation Success," in E. Redente et. al., *Symposium on Western Coal Mining Regulatory Issues: Land Use, Revegetation, & Management*, Colorado State University Range Science Department, Science Series No. 35, August 1983, pp. 31-35.

itor the reclaimed area during a period comparable in length to the climatic cycle over which baseline data were collected. The means of the baseline and monitoring samples could then be compared with 90 percent confidence intervals. This would necessitate a longer period of sampling than the mandated 2 years at the end of the liability period, however.

Technical Standards.—Technical standards set quantitative goals for vegetative characteristics based either on the range of values for particular characteristics found on similar lands in the region, or on negotiations between the operator and the State regulatory authority that consider the requirements of the postmining land use, demonstrated success of revegetation practices in the region, and baseline vegetation values. Technical standards are most often used for cover and production when baseline conditions are unacceptable due to poor land management. Woody plant density and species/lifeform diversity are commonly judged with negotiated technical standards.

Realistic and fair selection of the technical standards that reasonably may be expected in an area require a substantial amount of data. Soil Conservation Service (SCS) or Bureau of Land Management (BLM) range site data may be used for this purpose (see ch. 5), as may accumulated historical record data as it is developed in a region. For example, in Campbell County, Wyoming, most vegetation types have been sampled every year since 1977. Therefore, sufficient data should now be available to establish minimum regional performance standards for vegetative parameters, if such a standard were deemed desirable by the regulatory authority (6). However, differences in data-collection methods and climatic conditions from site to site and year to year could make it difficult to translate these data into technical standards.

Similarly, because SCS range site data are from climax communities—a level of development that revegetation 9 or 10 years old might not be able to match—they can produce unreasonably high technical standards. Even where appropriate data are available, technical standards as currently used do not make adjustments for climatic conditions in the test year. Data used to derive technical standards often include ranges of production from most favorable to least favorable years, but a direct mathematical adjustment tied to climate is not available yet.

Technical standards may reduce costs of vegetation data collection by eliminating the need for reference or control area sampling. Technical standards also may be used to set higher standards than baseline conditions when the premining vegetation has been depleted by overgrazing. In addition, technical standards can be used in areas where reference areas are unavailable. As mentioned above, the most common present and potential use of technical standards, however, is for evaluation of woody plant density and species/lifeform diversity (see box 7-B).

Hydrology Standards[6]

Although SMCRA emphasizes the hydrologic aspects of reclamation, performance and design standards, and bond release criteria for restoration of hydrologic systems, are not nearly so detailed as they are for revegetation. The regulatory authorities have not applied any hydrologic performance standards as yet (see below), with the exception of the restoration of surface drainage systems which are sometimes included in Phase I bond release. Evaluation of restored drainage systems is a straightforward comparison of regraded topography with the approved postmining topographic map. Other aspects of hydrologic evaluation will, however, require the regulatory authorities to formulate more specific directions about application of the standards. In none of the States and at none of the 20 mines reviewed for OTA are clear and complete hydrologic evaluation criteria in place.[7]

Box 7-B.—A Proposed Technical Standard for Shrub Density

Spatial heterogeneity of shrub cover greatly increases its contribution to wildlife habitat. However, baseline and reference area data usually record only the overall average of stems per acre. When such data are used as performance standards, the result is often a uniform distribution of shrubs to the required density, and the "clumping" of shrubs desirable for wildlife is lost. To address this problem, Wyoming has proposed a technical standard for shrub density which states that 10 percent of the reclaimed surface should have shrub densities of at least one stem per square meter (4,050 stems per acre). The remaining 90 percent of the area should have shrubs included in the seed mix, but there are no shrub density performance standards that must be met.

Surface Water.—Surface water standards in SMCRA deal with water quality and quantity, as well as drainage systems. The reclamation plan must include general information regarding backfilling and grading and a detailed description of the measures to be taken for the protection of surface water quality and quantity. The performance standards require operators to minimize disturbances to the quantity and quality of surface water and emphasize avoidance of deleterious materials and increased TSS and TDS levels. The standards also require operators to grade restored land so as to control erosion.

The Federal regulations include design criteria for the capacity of both "permanent diversions" (diversions of perennial and intermittent streams) and "diversions of miscellaneous flows" (ephemeral streams) (19). The regulations also specify design criteria for sedimentation ponds (21), and require that water discharged from these ponds be in compliance with the effluent limitations promulgated by the Environmental Protection Agency (EPA) (17,19).

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[6] Unless otherwise noted, material in this section is adapted from reference 14.

[7] Each of the case studies in reference 14 contains a discussion of the hydrologic evaluation criteria for that case study mine. In all cases, the criteria are at least vague and, occasionally, nonexistent.

Bond release criteria for surface water are also quite general.[8] All States have regulations that require evaluation of: 1) whether pollution of surface water is occurring, whether such pollution is likely to occur in the future, and the estimated cost of abatement; and 2) whether lands are contributing suspended solids to streamflow or runoff outside the permit area in excess of requirements set by applicable State or Federal laws (see box 7-C). Although erosion is the primary contributor to elevated TSS levels, evaluation of sedimentation that affects surface water has not measured erosion rates. As discussed in chapter 8, field data on sediment yields (the total amount of eroded material that reaches a control point) are needed to demonstrate that alternative methods of sediment control are as effective as sedimentation ponds.

Box 7-C.—Application of TSS Standards

It is not yet clear how regulatory authorities will apply the TSS performance standard. In Colorado and Wyoming, suspended solids requirements are set by premining or baseline levels of suspended solids. In North Dakota, Montana, and New Mexico, State and Federal authorities have established nonsite-specific standards of acceptable TSS for all perennial streams. Both types of standards have limitations. Adequate premining and baseline data on TSS levels are not always available and TSS standards have not been set for the small ephemeral streams which constitute the great majority of streams affected by mining in the West. In addition, no standards have been set on data collection methodologies to be used when evaluating TSS levels (see ch. 5). TSS levels vary greatly with the climatic changes that cause changes in flow rate and level, such as precipitation and snow melt events. TSS data may also vary greatly with the sampling methodology used and the point in the channel samples are taken from. These aspects of the evaluation procedure will have to be defined by regulatory authorities before suspended solids standards can be applied.

Compliance with an approved mining and reclamation plan provides regulatory authorities with the primary means to evaluate designs of restored surface drainage systems (see ch. 6). All designs submitted are evaluated during the permit application review and approval process, and progress on channel reconstruction is reviewed during compliance monitoring.

Groundwater.—There are no standards for evaluating restoration of spoils aquifer hydraulics and recharge, and no official numerical standards for evaluating postmining groundwater quality. Current bond release criteria for groundwater restoration are vaguely tied to whether or not pollution of subsurface water is occurring. However, "pollution" in this context is not defined quantitatively by any State program.

Due to the lack of numerical standards, groundwater quality impacts usually are analyzed with respect to use-suitability criteria established by EPA (see table 7-3). Spoils water is examined to determine if its quality is suitable for the same uses as premining groundwaters. Operators are concerned about one aspect of evaluation using these use-suitability criteria. An operation that disturbs water with TDS levels at the low end of the range of suitability for a particular use can add a large amount of solids without exceeding the criteria, but an operator affecting water at the high end of a range can add very little. For example, an operation disturbing an aquifer with premining TDS levels of 1,499 mg/l, which is unsuitable for domestic use but suitable for all

Table 7-3.—Maximum Recommended Total Dissolved Solids Concentrations in Water for Various Uses

Use	Maximum TDS concentration (mg/l)	
Domestic	500	(recommended)
	1,000	(maximum)
Livestock	3,000	(for all classes of livestock)
	5,000	(excluding poultry)
Irrigaation	500	(for all crops and soils)
	1,000	(for all but sensitive crops)
	2,000	(may adversely affect some crops and requires careful management)
	5,000	(only for salt-tolerant plants on permeable soils with careful management)

SOURCE: Western Water Consultants, "Hydrologic Evaluation and Reclamation Technologies for Western Surface Coal Mining," contractor report to OTA, August 1985.

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[8] See reference 14, table 5, for a summary of references in the State regulations to hydrologic criteria for bond release.

classes of livestock, can double TDS concentrations and remain within these criteria. An operation disturbing an aquifer with TDS levels of 2,999 mg/l, which is the top of the range suitable for livestock use, can add nothing to TDS concentrations, however.

Groundwater quantity and spoils-aquifer hydraulic characteristics usually are evaluated by determining whether the spoils will permit reestablishment of premining groundwater flow patterns, and whether they will provide water to wells in sufficient amounts to restore the uses supported by the premining coal and overburden aquifers. Because these wells typically supplied livestock and domestic uses, small well yields (less than 5 gpm) usually are adequate.

Mine operators must apply for permit renewals in 5-year intervals. If monitoring of spoils-water quality or aquifer testing of the spoils indicates that problems are developing, corrective measures can be worked out to forestall problems at bond release and final success evaluation (14).

Evaluation of groundwater restoration is often complicated by the very long periods of time required for spoils aquifer recharge in the West. Even after groundwater levels are reestablished in an aquifer, groundwater quality will remain variable for an indeterminate amount of time while chemical equilibrium is reestablished. Therefore, it is unclear whether application of quantitative evaluation standards for groundwater restoration will always be possible or reasonable.

Alluvial Valley Floors.—The general performance standard for AVFs in SMCRA is that essential hydrologic functions (EHFs) must be restored. Because these functions are described in detail in baseline studies (see chs. 5 and 6), the intensive premining data establish performance standards for AVF restoration. Thus, restoration of EHFs can be demonstrated by comparing data for the reconstructed AVF with the baseline standard. Reclamation of an AVF under SMCRA has not yet been completed in any of the five States, so details of the evaluation process have not been worked out. For example, no thresholds of statistical comparability have been established (e.g., the "90 percent with 90 percent confidence" standard established for vegetation) to define how close to the baseline the restored EHFs must be.

The timeframe within which restoration of EHFs must be judged also has not been specified in any State. As with many other aspects of surface and groundwater restoration, it may be many years after reclamation activities are complete before the hydrologic system achieves approximate steady-state conditions. One mine reviewed by OTA has taken special measures to hasten the resumption of subirrigation and other EHFs on a restored AVF to facilitate evaluation of their restoration (see ch. 3, box 3-K).[9]

Soils and Overburden Standards[10]

Standards for evaluating reclamation success for soils and overburden are very limited. Existing standards are based on approved designs; "performance" of soils and overburden is assessed indirectly, through evaluation of revegetation and hydrologic restoration.

Soils.—In most cases, soil reconstruction is considered to be successful if the postmining soil is as thick as predicted in the baseline study, and the lifts (if required) are in the correct order.[11] Erosion must not exceed premining levels or contribute additional suspended solids to streamflow outside the permit area (see discussion of hydrology standards, above).

The regulatory authorities usually evaluate erosion of the redressed topsoil quantitatively. Two methods of erosion measurement used at mines reviewed by OTA are described in chapter 5, box 5-E. Federal and State regulations require that rills deeper than 9 inches on regraded and topsoiled areas be filled, graded, or otherwise stabilized.

The regulatory authority also will evaluate compliance with any special stipulations regarding soils. Several permit applications reviewed by OTA had stipulations regarding soil monitoring for salinity, sodium adsorption ratio, and pH. However, in some cases, the stipulations did not specify the value at which each of these parameters should be considered a problem. The stipulations also did not always say how problems should be treated if discovered.

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[9] See reference 14, case study J.

[10] Unless otherwise noted, material for this section is adapted from reference 12.

[11] Montana and North Dakota both require two lifts.

Recent research on soil standards focuses on the reconstruction of a viable root zone. In North Dakota, researchers are developing methods for evaluating the properties of the reconstructed root zone that will help compensate for the shortcomings of reference areas. In addition, evaluation of soil parameters is an attractive method of gauging land productivity in areas where land is being reclaimed to cropland (e.g., in the Midwest and North Dakota), because of the variability in production due to climatic factors. However, methods to conduct such evaluations are still in their experimental stages and have not been accepted by the North Dakota regulatory authority (3).

Overburden.—Evaluations of overburden replacement emphasize prevention of problems because success is difficult to predict conclusively. Furthermore, cures for the inadvertent placement of material that may be detrimental to revegetation or postmining water quality may be prohibitively expensive because they involve removing and redistributing large amounts of material. Regulatory authorities therefore rely heavily on formulation of good spoils-handling plans in the permits to ensure proper handling of potentially deleterious spoils material, and on frequent inspection during mining to ensure compliance with approved plans.

As discussed in chapter 5, it is fairly common in the West for operators to sample the surface of recontoured spoils to check for unsuitable material in the root zone (usually considered to be the top 4 feet of spoils). If a problem is found, steps can then be taken to treat or cover deleterious material. During bond release, each of the five States evaluates the data from these spoils samples by applying the same unsuitability criteria that they use for baseline evaluations of overburden suitability (see ch. 6). Surficial spoils sampling for bond release is the norm in Montana and Wyoming. The North Dakota regulatory authority rarely requires spoils sampling because they require so much soil cover that unsuitable overburden usually will not be a problem. In Colorado, surficial spoils sampling is used to evaluate reclamation only if it is required in a permit stipulation because a potential problem was recognized before or during mining. In New Mexico, spoils sampling is not the norm, but in the two mines reviewed by OTA, baseline investigations showed all of the spoils to be unsuitable. Therefore, sampling the regraded material was considered unnecessary.

Where the surficial spoils are sampled, all State regulatory authorities consider a single round of sampling sufficient; nowhere are spoils routinely monitored over time. Consensus among the regulatory authorities is that monitoring following topsoiling should be required only if revegetation problems develop. This approach ignores the risk, however, of changes in spoils suitability, particularly in areas with potential for sodium migration.[12]

Wildlife Standards[13]

The regulatory agency personnel in the five States reported that they have no quantitative performance standards for judging the success of wildlife mitigation measures. Instead, regulatory authorities assess habitat restoration by evaluating the various habitat components, such as revegetation, topsoil placement, and water quality. Operators usually monitor wildlife use of restored habitats, but lack of confidence in wildlife data makes all parties reluctant to use monitoring data for quantitative evaluations (see ch. 5). Another obstacle to wildlife performance evaluations is the varying effect vegetation succession has on wildlife use of reclaimed land. Early- to mid-successional plant communities often benefit more—and different kinds of—wildlife than do late-successional and climax communities. Because floral succession through these vegetation stages often takes decades, wildlife use of reclaimed land will not reach premining levels of diversity and population density during the bond liability period.

Some wildlife mitigation measures must be evaluated with design standards; for example, range fencing that permits pronghorn passage, road underpasses and overpasses for wildlife, nesting structures, and raptor-safe power lines

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[12] Recent work done in Montana increases cause for concern that sodium migration through spoils over time will not be detected through one-time spoil sampling programs (3).

[13] Unless otherwise noted, material in this section is adapted from reference 1.

Photo credit: Jenifer Robison, OTA staff

Rockpiles are used to simulate surface features such as rock outcrops that are destroyed in mining. However, quantitative design standards to facilitate optimum establishment of features such as rockpiles have not been established.

(see ch. 3, fig. 3-11). The U.S. Fish and Wildlife Service currently is developing design standards for raptor nest and highwall manipulations. However, design standards do not exist for many of the more commonly required habitat enhancement or replacement measures. There is general agreement that features such as rockpiles and shrub patches are beneficial to wildlife, but designs for optimum establishment of these features are less obvious. Lack of quantitative design standards for these features also make evaluation of compliance difficult for regulatory authorities. Questions that must be answered include: How big should these features be? How many of them should there be? In what configuration should they be placed over the landscape? Without some numerical parameters for constructing these features, it is difficult for operators to know how to install the mitigation features in a way that will satisfy the regulatory authority, and to have confidence in the usefulness of the habitat enhancement measures required in permitting.

STATE EXPERIENCE WITH RECLAMATION EVALUATION AND BOND RELEASE

Reclamation under SMCRA and the approved State programs is a relatively new activity in the West. While no mines have completed their 10-year liability period, a limited amount of experience has been gained in some States with release of Phase I bonds. Each of the five Western States studied has a slightly different approach to bond release and success evaluation. This section presents a brief overview of bond release activity and the development of bond release criteria in the study States.

North Dakota[14]

To protect the rich soil resource in its State, the Public Service Commission (PSC) in North Dakota divided the SMCRA Phase I release into two parts. To receive the initial 40 percent of the bond, operators must backfill, grade, and establish drainage control to the PSC's satisfaction. After these activities have been judged successful, operators

Photo credit: Office of Surface Mining

Because of the predominance of cropland in North Dakota surface mining areas, the bond release procedures there emphasize reconstruction of the soil resource.

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[14] Unless otherwise noted, this discussion is based on reference 9.

must topsoil the regraded surface to qualify for another 20 percent of their bond. Up to another 20 percent of the bond may be released after revegetation has been established. The PSC may only release the remaining 20 percent or more of the bond after the 10-year liability period has elapsed and it judges all reclamation activities to be successful.

North Dakota law establishes a Reclamation Advisory Committee to oversee the two final stages of bond release. The Committee consists of representatives from PSC, SCS, the North Dakota State agricultural extension service, and others knowledgeable about reclamation. When an operator wishes to start the 10-year liability clock, the committee inspects the reclaimed site. If the committee judges revegetation to have been reestablished successfully at that time, the initial revegetation portion of the bond is released and the 10-year liability period begins. During the liability period, the operator must manage the land with practices considered normal husbandry for the designated postmining land use. At the end of the 10 years, the committee reinspects the reclaimed site and decides whether the remainder of the bond should be released.

A few bonds have been partially released for grading and backfilling in North Dakota. Criteria used to judge success of these activities are fairly straightforward and usually are applied by mining engineers. Topographic maps are used to inspect for AOC and for adequate reconstruction of drainages according to approved reclamation plans. Sampling for deleterious material in the postmining root zone or water table is not routinely required. The regulatory authority generally relies on early identification of these materials from baseline data submitted with the permit application (see ch. 5), and on frequent inspections during mining and reclamation to ensure that any such materials have been handled properly. In addition, the requirement for 48 inches of soil cover over regraded spoils reduces concerns about deleterious overburden. Sampling may be required on a case-by-case basis if there is reason to believe that any material may be deleterious to plant growth.

The PSC is preparing guidelines for judging the reestablishment of revegetation. None of the mines studied has applied for the revegetation stages of bond release yet, although the first of these could be filed in 1986 if weather conditions are favorable.

Montana[15]

Montana has not released any phases of post-SMCRA bonds. At the time of this writing, however, the Department of State Lands (DSL) had two applications for Phase I release pending, and expected another application in June, 1986. One of the pending applications had been submitted twice, and both times was returned to the operator for further work. DSL has tried to formulate criteria for Phase I release (up to 60 percent), which in Montana covers backfilling, topsoiling, regrading, and drainage control. In this attempt, however, DSL found more exceptions than rules, and so is relying to a large extent on case-by-case evaluations of success.

In general, DSL inspects sites during Phase I release for obvious design features: AOC, stable drainage structures, adequate topsoil thickness as approved in the permit. If permit stipulations require sampling of recontoured spoils, the monitoring data must be submitted and evaluated prior to Phase I release. In addition, DSL uses the Phase I inspection to reexamine compliance with the mining and reclamation plan and to ensure that modifications—which are inevitable during the course of any mining operation—have been fully taken into account in the mine's long-range planning. In particular, DSL checks to ensure that, where an operator is seeking bond release on only a portion of the site, as is common at large Western mines, modifications made in the overall mine plan will not require the operator to redisturb the site.

DSL does not expect to receive any applications for Phase II bond release on revegetation for another 3 to 5 years. Unlike the other States, where Phase II revegetation is considered to be only a preliminary surface stabilization measure, the Montana regulations require all of the revegetation success standards to be met prior to release of the Phase II bond (11). Montana also applies the 10-year liability clock on revegetation in Phase II rather than Phase III. The regulations contain detailed standards for revegetation success in this second phase of bond release. These include:

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[15] Unless otherwise noted, this discussion is based on reference 7.

- the use of reference areas under management practices similar to the revegetated area, and grazed at no more than 50 percent of capacity, as standards for judging reclamation success;
- evaluation of weighted productivity and weighted canopy cover by morphological class (the mathematical formulae to be used to calculate these are specified in the regulations);
- evaluation of weighted diversity by species (the mathematical formula to be used is specified in the regulations);
- evaluation of permanence and seasonality of vegetation; and
- analysis of potential toxicity of vegetation to animal consumers, where suspected.

Up to 25 percent of the bond may be released during Phase II, leaving 15 percent (or more, if less than the maximum was released in previous phases) to be released when the regulatory authority finds that all reclamation activities have been completed in accordance with the approved reclamation plan.

Wyoming[16]

Wyoming's bonding system differs slightly from the other States in that it is based on the intensive annual review the Wyoming Department of Environmental Quality (DEQ) conducts for each mine. Under Wyoming's system, each surface coal mining operation in the State has two different bonds.[17] The **area bond** covers only the cost of backfilling any portions of the pit that will remain unfilled during the coming year. The area bond is adjusted following annual DEQ review to reflect both progress in backfilling and progress of new disturbance. Therefore, if an operator backfills and disturbs at the same rate, his area bond will remain unchanged. Area bonds may only be adjusted upward—a protection for the regulatory authority to ensure that sufficient funds are available to cover default at any time.

The **incremental bond** covers all other features of reclamation; it is increased annually to reflect costs of reclaiming the amount of acreage that will be disturbed in the coming year. DEQ does not consider reclamation of previously disturbed acreage in the annual review of the incremental bond. Rather, release of the incremental bond follows a pattern similar to that outlined in SMCRA: 60 percent of the incremental bond may be released after regrading, topsoiling, and drainage control have been completed. Another portion of the bond (amount to be determined by the regulatory authority) may be released after initial revegetation, as determined by species composition, which must be similar to that of the approved seed mix. The remainder of the incremental bond may only be released after the operator has completed all reclamation activities in compliance with the permit, the regulatory program, and SMCRA.

Although DEQ has been reviewing and adjusting area bonds each year, no Wyoming operators have yet applied for release of any part of an incremental bond. Definite criteria for evaluation of the different phases have not yet been formulated. DEQ personnel do not anticipate much controversy or difficulty in the Phase I evaluation. As in other States, the criteria at this phase are fairly clear engineering design criteria.

DEQ inspects mine sites frequently during mining and reclamation to monitor the operators' progress. Moreover, after regrading an area, an operator may request that DEQ inspect it for acceptability of drainage topography, AOC, and presence of unsuitable spoil material at the surface. Before the inspection, operators supply data from recontoured spoils samples. This pre-topsoil inspection is not mandatory, but most operators request it because it can help identify problems in this expensive part of reclamation early so as to avoid the greater expense of fixing problems after topsoiling.

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[16] Unless otherwise noted, this discussion is based on reference 16.

[17] The Federal regulations that allowed "phased bonding" of this type have recently been declared inconsistent with sec. 509(b) of SMCRA by the U.S. District Court because they do not require full bond for all aspects of reclamation for the duration of the mining and reclamation operation (5). The regulations have been remanded to the Department of the Interior, but until new Federal regulations are promulgated and, if challenged, are accepted by the courts, the State of Wyoming plans to continue to bond under its current system, as outlined in its approved permanent program (16).

DEQ does not anticipate receiving any applications for Phase II release of the incremental bond for several years, but is working now on formulating criteria for this phase.

Colorado[18]

The Colorado Mined Land Reclamation Division (MLRD) has released one Phase I portion of a bond, and is reviewing two more applications for Phase I bond release. The Phase I release is for backfilling and grading only, and is based on standard engineering principles. However, MLRD's experience at the northwestern Colorado mine where Phase I release has been granted suggests that judging success for Phase I bond release may not be so straightforward as it appears.

MLRD's review of that Phase I bond release application concluded that all of the required criteria had been met. Therefore, MLRD was prepared to release 60 percent of the applicant's bond in the spring of 1984, when a major slump occurred on the regraded site. Much of the surface coal mining in northwestern Colorado occurs on fairly steep slopes, many of which contain mica shales dipping at angles semi-parallel to slope topography. The instability of these formations is well known and routinely taken into account in road and building construction, as well as in mining. Furthermore, precipitation had been much higher than normal during the years prior to the mine's application for Phase I release. Therefore, slumps were common in this area of Colorado, both in areas of little or no human activity and where the land had been disturbed (e.g., along highways).

Because MLRD determined that, at the time of application, the site met the criteria for bond release, MLRD released 60 percent of the bond on the area despite the slump. MLRD maintains, however, that the operator retains liability for the slump because it was the result of poor reclamation, and wants the operator to repair the damage. On the other hand, the operator argues that the slump was the result of unusual natural conditions unrelated to mining, and therefore is an act of God for which the operator may not held liable for repair. The remaining 40 percent of the bond is insufficient to repair the damage. The liability issue had not been resolved as of this writing.

One condition of MLRD's bond release was that the operator conduct a study of the reasons for the slump, to be submitted to MLRD in August 1985. Prior to the slump, the operator had been granted a permit to mine an adjacent area which contains similar steep formations. If the operator cannot diagnose the cause of the previous slump, and therefore cannot develop satisfactory mining and/or reclamation techniques to prevent another similar occurrence, MLRD feels it will be forced to withdraw this permit. Despite the operator's claim that the slump was unrelated to mining, the regulatory authority suspects that it may have occurred, at least in part, because of increased water infiltration into the spoils as a result of the mining methods used at this site. Revising the mine plan and/or draining the spoil might make mining on the adjacent similar areas possible. Detailed analysis of the problem must wait until the operator's report on the slump has been completed.[19]

In Colorado, the second phase of the bond is released after topsoiling and revegetation to a level sufficient to prevent erosion. The State has some Phase II applications pending and is in the process of formulating specific standards for evaluating them. Because MLRD views Phase II release as a judgment that the surface has been stabilized, these standards will emphasize vegetative cover to a specified level and a demonstration that sediment levels in water from reclaimed areas are not greater than baseline levels.

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[18] Unless otherwise noted, this discussion is based on reference 2.

[19] Although the site discussed here originally was mined prior to the passage of SMCRA, it was repermitted under Colorado's permanent program, bond was released according to SMCRA-mandated standards, and similar areas have been permitted for mining under SMCRA. For these reasons, the site is relevant to this study.

New Mexico[20]

The New Mexico Mining and Minerals Division (MMD) has not received any applications for bond release under its SMCRA program, and has not formulated standard criteria for release because it intends to judge applicants on a case-by-case basis to give proper consideration to the wide variability among surface coal mining sites in the State. MMD considers judging Phase I release, which includes backfilling, grading, drainage control, and topsoiling in New Mexico, to be a fairly straightforward engineering problem. Inspections for proper handling of acid- and alkaline-forming materials, which are very common in the overburden in New Mexico, will be conducted throughout the mining and reclamation process to ensure that potential problems are discovered and dealt with before bond release. By keeping in close contact with operators throughout the reclamation process, MMD does not anticipate any surprises at Phase I bond release inspection.

MMD expects judging success at the second phase of bond release to be more difficult, and their personnel are trying to formulate standards now. Because, historically, so much of the land in New Mexico has been poorly managed and overgrazed, baseline data often represent undesirable conditions. Therefore, suitable reference areas are difficult to find, and MMD is relying on a mix of methods while they try to formulate technical standards for cover, species diversity, shrub density and other vegetative parameters. At some sites, historical record evaluations can be used for the plant communities that are less likely to have been damaged by poor land management practices, particularly for evaluating woody plant density. At other sites, suitable reference areas may be available for some plant communities but not for others. For example, one mine has suitable reference areas for herbaceous communities, but not for woody plants because premining woody plant density was deemed too high to be compatible with the postmining land use. Technical standards will be used to judge success for woody plant communities. Thus, each mine is likely to have its own mix of evaluation methods and standards depending on peculiarities of the site.

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[20] Unless otherwise noted, this discussion is based on reference 8.

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Chapter 8

Technical Issues in Western Surface Mine Permitting and Reclamation

CHAPTER OVERVIEW

OTA's assessment of Western surface mine permitting and reclamation highlighted several technical issues that have significant implications for the long-term success of Western reclamation. These issues encompass the technologies, data, and analytical methods for identifying acid-forming overburden; techniques for controlling sediment in runoff; soil handling methods that could improve revegetation; achieving revegetation of woody plants; defining and maintaining the postmining land use; and designing the postmining landscape.

Some of these issues address areas in which OTA's analysis of surface mine permitting and reclamation indicated additional research or reclamation experience is necessary to resolve uncertainties about the long-term success of reclamation. For example, baseline studies indicate that some Western mine spoils may contain material with a potential for acid-formation, which could be detrimental to revegetation. The magnitude of possible impacts cannot be estimated reliably, however, because available techniques for predicting the acid-base potential of spoils were developed for Eastern mining conditions, and their reliability when applied to the very different climate, hydrology, and other conditions in the West has not been demonstrated. Ongoing research is making progress at developing a more reliable technique, but in the meantime, estimates of acid-forming potential in the West may be overly conservative, increasing the cost of reclamation.

Meeting uniform high woody plant density standards is a major concern throughout the study region. While the technology of shrub reestablishment has advanced substantially in recent years, operators in many areas still find it difficult to establish more than one or two species. At the same time, high woody plant density has long been a source of aggravation to ranchers, who have undertaken large-scale rangeland management programs to thin or kill woody species, frequently with financial or technical support from Federal land management agencies. Additional research and reclamation experience are needed on the relative values of different densities and groupings of woody plants for the postmining land uses of rangeland and wildlife habitat.

A second set of issues discussed in this chapter highlights reclamation techniques that are accepted practice or are required by law or regulations, but which may themselves cause adverse environmental impacts. **Sedimentation ponds are considered the best technology currently available to control the discharges of total suspended solids that result from accelerated erosion caused by mining and reclamation activities. But sediment control ponds increase the land that must be disturbed during mining and reclamation, can cause reduced streamflows and channel degradation downstream, and are expensive to build and maintain.** Additional data are needed on sediment yields and on the effectiveness of alternative means of control before the continuing need for sedimentation ponds can be evaluated fully.

A third set of issues highlights emerging practices that OTA found to improve the quality of reclamation. **Innovation in soil handling methods has significantly improved the prospects for the long-term success of revegetation. Furthermore, optimization of soil handling can reduce the costs of reclamation.** Yet, in some casees, operational and regulatory considerations constrain the widespread adoption of such techniques.

OTA also examined **the concept of "landscape diversity," which recognizes the mosaic nature of Western landscapes resulting from localized**

differences in the physical environment, plant communities, wildlife populations, and land uses. While no general requirements related to landscape diversity currently exist, requirements for specific mines have been established on a case-by-case basis, primarily in relation to vegetative communities.

Finally, **OTA found a general lack of attention to the detailed quantitative characterization of pre- and postmining land uses that is required by the Surface Mining Control and Reclamation Act (SMCRA) for the permit application package.** Lack of specificity and quantification in these characterizations can adversely affect postmining vegetative (and landscape) diversity, the implementation of surface owners' or management agencies' land use recommendations, and the difficulty and cost of reclamation. Moreover, at mines where reclaimability is an issue during permitting, a much more vigorous approach to characterizing premining land uses and to predicting the capability and productivity of the reclaimed surface is necessary.

ACID POTENTIAL IN WESTERN MINE SPOILS[1]

One objective of methods used to design the replacement of overburden is to identify strata that could be detrimental to revegetation, including potentially acid-forming materials within the premine overburden, in order to devise a strategy by which the deleterious potential of these materials will be neutralized. The principal means of accomplishing this are selective placement in the post-mine spoils to prevent saturation with surface or groundwater, and/or burial with sufficient depth of cover to block infiltration of surface water and prevent the deleterious material from migrating upward to the root zone.

Regardless of the specific setting or the mining technique, mining rearranges the natural sequence of coals and associated rock strata and places them in contact, at least temporarily, with atmospheric conditions. In that new environment, a host of interrelated factors, including oxygen, humidity, and iron bacteria, combine to accelerate the rock-weathering processes which, in turn, may cause radical changes in the chemistry of water contacting the weathering strata. In some cases, mineralogy is such that the rock remains inert and neither acid nor alkaline conditions are produced.

Acid drainage from mining is a common problem in the East, where groundwater systems generally are more active than in the West, and recharge rates much greater. The overburden from Eastern coal mines contains significant amounts of sulfur as inorganic iron pyrite (FeS_2). In an oxidizing environment, much of the sulfur in the pyrite will combine with water and oxygen to form sulfuric acid (H_2SO_4). The humid climate in the East accelerates the oxidation of sulfur compounds by ensuring there is a constant supply of water to saturate the spoils and thus a constant supply of hydrogen ions to form sulfuric acid. The pH of surface or groundwater supplies in contact with the pyrite-bearing strata will be lowered unless the surrounding materials have a large buffering capacity. As the pH is lowered the water becomes an acidic solution with a high content of sulfate and iron that is unsuitable for all domestic and agricultural uses. Moreover, the solubility of other mineral constituents of the soil or rock will be affected by a lowered pH and potentially toxic materials (e.g., arsenic, barium, cadmium, chromium, lead, mercury, selenium) can go into solution, further contaminating the water supply and rendering it harmful to vegetation or to animal and human populations.

The potential for acid formation in the West is different for several reasons. First, the climate is generally arid or semiarid, which limits the amount of water available for oxidation of sulfur compounds. *Below the water table,* the oxidation process is not very active because the availability of oxygen in the geological material there is severely restricted by the very low solubility limit for oxygen in water. However, the time scale associated with the evolution of this hydrogeochemical process may vary over years, decades, or possibly centuries and cannot be predicted with much confidence with existing knowledge. If pyritic materials are inadvertently placed *above the water table,* oxidation can be very active and rapid provided that the pore spaces in the material receive oxygen, because the subsequent infiltration of rainfall or snowmelt causes the oxidation products and associated weathering products to go into solution. They are then able to move downward where they become part of the dissolved solids in the groundwater systems.

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[1] Unless otherwise noted, the material in this section is adapted from references 2, 4, and 6.

Second, while the sulfur in Western overburden occurs in organic compounds as well as in inorganic iron pyrites, **Western overburden typically has a high buffering capacity.** Calcite and dolomite, common overburden constituents, are soluble in an acidic solution and the carbonates combine with available hydrogen to form bicarbonates that raise the pH and neutralize the acidity. From an environmental viewpoint, alkaline drainages originating from calcium-magnesium carbonate systems are normal in the West, and thus do not harm the hydrologic regime. A rising water table that inundates pyrite-rich zones in the spoils is another mechanism by which pyrite oxidation is inhibited. A fluctuating water table can promote weathering in the zone of fluctuation, but if no replenishment of oxygen from the atmosphere occurs, severe degradation of groundwater quality is unlikely.

The following must be determined to predict the potential for acid formation:

- the organic content of the pre- and postmining soil;
- the porosity and permeability of the recontoured spoils, to aid in predicting available oxygen for oxidation;
- the predicted level of the postmine water table and in what general time frame recharge will occur (1, 10, 50, 100, 500 years);
- the percentage of pyrite in the overburden, to give a gross indication of the potential for acid formation; and
- the buffering capacity of the overburden, to allow a gross indication of the potential for neutralizing acid.

A test has been devised that uses these data and analyses from Eastern overburden materials to predict their acid-forming potential. This procedure leaches overburden samples with hydrogen peroxide to extract sulfur forms; it assumes that all sulfur forms will be oxidized completely. In the West, however, a large fraction of the sulfur is in less reactive organic forms, and the assumption that all sulfur forms will go from a reduced to a completely oxidized state is not valid. These lab methods and the overburden suitability criteria derived from them have been proven reliable for predicting the potential for acid production in Eastern mine spoils through years of application.

Applicability of the same methods and unsuitability limits has not been proven in the West. The chemical and physical conditions that contribute to the potential for acid formation are sufficiently different in Western coal regions to invalidate the lab results and, therefore, the interpretations from which suitability limits are established. The issue is one of understanding the geochemistry of Western overburden and the range of conditions that exist in the various coal fields, and of devising a laboratory method that yields reliable results from which valid overburden suitability criteria can be established.

Baseline studies similar to those listed above have demonstrated that there are conditions under which acid formation could occur in New Mexico and in the Wyoming portion of the Powder River basin.[2] The Wyoming Department of Environmental Quality (DEQ) has acknowledged the potential for acid production in mine spoils since 1978. DEQ requires sample testing for determination of the acid-base potential (ABP) of overburden using a furnace-induction method that allows isolation of the reactive inorganic sulfur compounds. The calculation of acid potential still is based on the assumption that all reactions go to completion, however. In New Mexico, the soils and overburden are strongly alkaline, the climate desert-like, and sulfates appear primarily as gypsum in weathered strata.

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[2] It is unclear why the unknown potential for acid formation is not considered a problem in the Montana portion of the Powder River coal region.

Acid-forming strata have been documented at one mine, and ABP determinations are required for strata low in lime.

The potential for acid-forming material is low in the Fort Union coal region of North Dakota and Montana where soils are deep and more likely to be sodic. No ABP analysis is required in these areas. In Colorado, no special analysis or interpretation would be required unless there were a reason to suspect a problem (e.g., acid formation at nearby mines, or high concentrations of pyritic sulfur in the lab data).

While both the regulatory authorities and the operators acknowledge that the available techniques for estimating ABP may not produce reliable results when applied to Western overburden materials, the lab techniques will continue to be used until better methods are devised. As a result, the operators believe that some overburden material is being erroneously classified as unsuitable and that, as a result, they are being required to special handle the material needlessly (see box 8-A) and/or bury it more deeply than would ordinarily be the case. The regulatory authorities, while recognizing this possibility, believe that an overly conservative estimate of acid potential is better than failing to special handle deleterious material, with potentially much greater costs for reconstruction if revegetation problems arise.

Research currently being funded by the Western mine operators, both jointly and individually, is making progress in resolving this problem. The regulatory authority in at least one State, Wyoming, is prepared to rewrite State guidelines to reflect any changes in analytical techniques or overburden suitability criteria that may result from this research.

Box 8-A.—Special Handling of Potentially Acid-Forming Spoil[1]

The initial baseline overburden characterization at a large mine in the Eastern Powder River basin of Wyoming indicated that most of the overburden strata at this site have no deleterious qualities. The controversial ABP analysis suggested a few of the strata were potentially acid-forming; other overburden strata, in the vicinity of surface draws, were found to be saline. The overburden handling plan consists of a premining drilling program ("developmental drilling"; see ch. 5), special handling if indicated, the use of suitable near-surface material as the last 4-foot spoil lift, a recontoured spoil sampling program, and an additional 4 feet of suitable cover where necessary. The top bench of overburden is sampled on 500-foot centers prior to mining.

The data gathered in this drilling program are used to delineate unsuitable overburden, but also are used for other operational considerations. If these data identify unsuitable material comprising more than 20 percent of the bench, the material will be placed in backfill areas of heavy clay or silty shale to prevent further contact with air, surface water, reconstructed aquifers, topsoil, or vegetation. Coal partings and carbonaceous shales have been identified as potential sources of acid production under oxidizing conditions, so these materials will be buried below the projected backfill water table, where they will be quickly covered by compacted overburden and where, eventually, the void spaces will fill with water. The recontoured surface is backfilled to within 4 feet of the final level with run-of-mine spoil, then covered with the final 4 feet of near-surface, coarse-textured, oxidized, suitable spoil. This recontoured spoil surface is then sampled to assure suitability (see chs. 5 and 7). This general method of overburden characterization and special handling has been adapted for use at all of the truck and shovel mines in the Powder River basin of Wyoming, promoting a tendency for uniformity of approved procedures.

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[1] See case study E in reference 4.

SEDIMENT CONTROL[3]

Surface coal mining and reclamation operations in the Western United States can result in discharges of sediments to surface streams as a result of accelerated erosion caused by removal of the vegetative cover; topsoil stripping; and construction of stockpiles, roads, and other facilities. Discharges of total suspended solids (TSS) are regulated under SMCRA and the Clean Water Act.

The Clean Water Act requires the States to establish water quality standards to be achieved through effluent limitations on discharges from point sources. These standards and limitations are established and enforced through permits issued for point source discharges under the National Pollutant Discharge Elimination System (NPDES; see ch. 4). Effluent limitations for surface coal mines regulate discharges of TSS as well as iron, manganese, and pH. SMCRA also established a performance standard that requires a mine operator to prevent, to the extent possible using the best technology currently available, additional contributions of suspended solids to streamflow or to runoff outside the permit area.[4] Until 1982, the Federal regulations specified that the best currently available technology for the control of sediment is a properly designed and constructed sedimentation pond, as governed by both design and performance standards adopted by each State (see ch. 4).

In 1982, the Environmental Protection Agency (EPA) changed the Federal effluent limitation for sediment in discharges from sedimentation ponds (point sources) from 70 mg/l to a far less stringent settleable solids effluent standard of 0.5 ml/l to be used during precipitation events and for reclaimed areas. The original TSS standard of 70 mg/l still applies to all discharges when no precipitation is occurring and to pit water discharges. The 1982 EPA revisions also eliminated specific design and construction standards for sedimentation ponds. In 1983, the Office of Surface Mining (OSM) revised its TSS performance standard to be consistent with the new EPA rules. While most State regulatory programs still adhere to the more stringent suspended solids standard of 70 mg/l for point source discharges, the States eventually may revise their programs to incorporate the new settleable solids standard.

Sedimentation ponds historically have been the accepted technology for sediment control in all of the Western States studied except New Mexico, which is just beginning to develop a policy on the design and construction of runoff and sediment control structures. Previously, New Mexico had no design standards for sediment control structures, and New Mexico mines generally would construct a berm around the limit of disturbance to contain the estimated runoff from a 10-year 24-hour event. There is no discharge from the mines for runoff events less than the 10-year 24-hour event. In other States, the use of alternative sediment control measures (see below) has been permitted through case-by-case exemptions. For example, a mine in a plains area of southern Wyoming, where peak flows occur primarily from rainstorm runoff and all drainages are ephemeral, received a permit in June 1982 for a combination of sedimentation ponds and "other sediment control techniques." Contour berms and retention ditches were proposed and implemented as alternative sediment control measures to intercept surface runoff and trap sediment from disturbed areas.

Alternative means of maintaining sediment production at or below the level produced from undisturbed terrain include preventive measures and remedial designs. Preventive measures generally retard the velocity and reduce the quantity of runoff, thus reducing erosion rates. The primary preventive measure is topographic design of reclaimed slopes and drainage basins to reduce erosion rates, and thus sediment production. Complex slopes with upper convexities, middle straight reaches, and lower concave reaches have long been associated with the lowest erosion

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[3] Unless otherwise noted, the material in this section is based on reference 6.

[4] In this context, "best technology currently available" is defined in the Federal regulations as "equipment, devices, systems, methods, or techniques which will prevent, to the extent possible, additional contributions of suspended solids to stream flows or runoff outside the permit area, but in no event result in contributions or suspended solids in excess of requirements set by applicable State or Federal laws"(10).

Photo credit: Jenifer Robison, OTA staff

Cross-slope furrows and ditches can be used to retard the rate of runoff and divert runoff from reclaimed slopes and into drainage channels.

rates. Such slopes, in concert with drainage basin design that provides adequate drainage density and shorter slopes, will minimize long-term sediment production from reclaimed lands. Other preventive measures include revegetation, mulching, contour plowing, and use of rocky topsoil. Revegetation adds soil strength and surface roughness, retarding the velocity of overland runoff. Mulch retains surface water, enhances infiltration, and adds surface roughness. Contour plowing also adds surface roughness and enhances infiltration. Rocky topsoil produces an armor when it erodes, thus impeding further erosion, but is not allowed under the regulatory programs because rocks are considered to "contaminate" soil.

Remedial designs for actively disturbed and temporarily unstable lands can be constructed, where needed, at low cost and with minimal added impact. These techniques reduce erosion either by avoiding sensitive areas or by decreasing the amount of sediment in runoff. They include small diversion channels, porous rock or straw bale check dams, interceptor ditches, vegetative buffers, and diversion of runoff into the pit. Small channels divert runoff away from sensitive areas. Rock check dams and straw bale dikes act as temporary, permeable barriers to decrease streamflow velocity and cause sediment to deposit. Interceptor ditches are small, level trenches running across hillsides that slow surface runoff and promote sediment deposition. Strips of undisturbed native vegetation adjacent to disturbed land enhance sediment deposition and inhibit further erosion. Ditches placed around the toes of all topsoil and overburden stockpiles capture sediment as close to the source as possible.

The requirements for sedimentation control ponds are controversial in the Western United States because the ponds are expensive to build and maintain, because they increase the amount of land that must be disturbed during mining and reclamation, because most Western streams already have naturally high sediment levels, and because the cumulative effect of water storage in ponds at several mines can be a significant loss of water—the West's most scarce resource —to downstream users. Moreover, historically, the alternative sediment control techniques described above are considered proven technology and have been implemented successfully in agriculture, highway construction, and other land-disturbing activities.

Most of the streams in the semiarid West are ephemeral (flow only during runoff events). They originate in fine-grained sedimentary materials, derive all of their flow from surface runoff, and average 50 percent solids by weight. TSS concentrations as high as 1 million mg/l have been documented during runoff events. Runoff from mines or mine-water discharges into ephemeral streams can have adverse impacts on water uses that are especially sensitive to sediment loads. Also, if the sediment load is increased to the point that the sediment transport capacity of the stream is exceeded and its basic deposition processes fundamentally altered, the changes in the stream system can extend offsite. A significant decrease in sediment loads (e.g., when relatively clear water is released from ponds) also can have adverse impacts on ephemeral streams, because the unnaturally clear discharged water is erosive, and can result in channel incision or degradation downstream.

Perennial streams, on the other hand, originate in mountainous areas, receive discharge from groundwater, and derive their runoff chiefly from snowmelt. These streams, such as the Tongue, Yampa, and Missouri Rivers and their major tributaries, have naturally high-quality water. They typically support sport fisheries, municipal and domestic water uses, and large amounts of irrigation—all uses that would be affected adversely by an increase in sediment loads.

The cumulative effect of multiple sedimentation control ponds at several mines within a drainage basin can be a reduction in streamflows in both ephemeral and perennial streams. For example, the Wyoming DEQ's cumulative hydrologic impact assessment of mines north of Gillette, Wyoming, concluded that "the greatest cumulative impact to the surface-water system will be the reduction in streamflows resulting from the impoundment of runoff in sedimentation ponds and mine pits."(7) The greatest effect on the Little Powder River, as determined by DEQ from mine plan maps submitted by the permit applicants, will occur at its confluence with Rawhide Creek. Above this point, the flow of the Little Powder River could be reduced as much as 17 percent.

Such streamflow reductions could cause conflicts between mines and downstream irrigators who depend on flood flows to irrigate hay meadows. These potential conflicts have led DEQ to encourage the use of "alternative sediment control measures" such as straw dikes and porous check dams, which trap sediment but allow water to pass downstream, in lieu of conventional sedimentation ponds (8). This recommendation is made only where the receiving streams are ephemeral or intermittent, and therefore naturally high in TSS during runoff events. Perennial streams, which could be adversely affected by discharges high in TSS, still must be protected with sedimentation ponds. Therefore, it is unclear how these alternative measures would mitigate the streamflow reductions in perennial streams.

The advantages of alternative sediment control practices for discharges to ephemeral streams are highlighted in the Wyoming DEQ decision document on the proposed use of such practices at a mine in the southwestern part of the State. The decision document included a determination as to whether the alternative sediment control practices would encourage advances in mining and reclamation technology—one of the bases for permitting an experimental practice under SMCRA (see ch. 4):

> . . . sediment ponds are considered to be the best technology currently available to control sedimentation and protect receiving water quality. The coal mining industry as well as professional hydrologists and geomorphologists are often of the opinion that although sediment ponds may very well be the best technology currently available to protect perennial stream water quality in the Eastern United States, they are not the best, or most practical technology currently available to protect ephemeral stream water quality in semi-arid regions of the Western United States.
>
> The potential benefits of using alternate sediment control techniques instead of sediment ponds to protect the quality of receiving streams are as follows:
>
> 1. The lack of sediment ponds will lead to less land and wildlife habitat disturbance.
> 2. Alternate sediment control techniques will keep topsoil and subsoil on site where it is most useful for revegetation efforts.
> 3. Several alternate sediment control techniques result in less runoff which may lead to greater soil moisture, providing for more successful revegetation.
> 4. Alternate sediment control techniques may be more cost effective than sediment ponds.
> 5. The consequences of sediment pond dam failure and associated environmental degradation are eliminated.
> 6. Channel incision below sediment ponds, resulting from TSS concentrations well below ambient conditions, is eliminated.
> 7. Alternate sediment control techniques minimize the retention of runoff from undisturbed areas thereby providing more water to downstream water users (6).

Two sets of data are needed before the regulatory authorities will consider changing the strict requirement for technological sediment control on ephemeral streams to more flexible performance standards: empirical data on sediment yields (the total amount of eroded material that reaches a control point), and on the effectiveness of alternative means of control. The data on sediment yields from surface mining and reclamation can be obtained from premining baseline studies and from monitoring. Whether designing sediment ponds or planning alternative sediment control measures, it is necessary to estimate the amount of sediment that will erode from a watershed and be subject to transport downstream during a precipitation event. This can be accomplished through premining erosion pin studies or with other methods (see chs. 5 and 6). Small watershed studies currently are underway at a number of mines that also could provide empirical data on sediment yields during mining and reclamation.

Two mines in Wyoming currently are collecting data from experimental practices designed to demonstrate that alternative sediment control measures are as effective as sedimentation ponds in protecting water quality in ephemeral streams. One of these was approved for southwestern Wyoming in 1983 (see box 8-B) and one in the southern portion of the Powder River basin in 1985. As stated in the Wyoming DEQ decision document on the mine illustrated in box 8-B:

> To date, little, if any, meaningful suspended sediment data has been collected in areas being affected by coal mining activities in semi-arid areas of the Western United States. Therefore, this experimental practice will not only determine the adequacy of the alternate sediment control techniques proposed but will also adequately quantify ambient water quality conditions and streamflow conditions in ephemeral streams. This information, coupled with precipitation data, will greatly further the understanding of ambient and mining disturbed runoff conditions. In turn this can be used to adjust analytic techniques used by the mining industry and regulatory authorities in the development of mine drainage plans etc.
>
> Additionally, data collected as a result of this proposal will also be able to be used for the development and calibration of various hydrologic and sedimentation models . . . (6).

Box 8-B illustrates both innovative sediment control practices and state-of-the-art sediment and runoff monitoring techniques for ephemeral streams. The mine in this case study may benefit substantially from alternative sediment control because the high drainage density of the permit area would have required construction of over 200 ponds. Not all mines are faced with this situation, and for other mines the monitoring, reporting, and inspection requirements that accompany a formal experimental practice may outweigh any economic benefits of alternative sediment control.

As regulatory authorities become more comfortable with the use of state-of-the-art sediment and runoff monitoring techniques and with alternative sediment control measures, and as the needed data become available, more mines may be able to use alternative sediment control practices without the extensive requirements for an experimental practice. As the result, water quality in ephemeral streams will be protected while creating smaller impacts on the availability of water for downstream users—a critical consideration in the arid and semiarid West.

A continuing uncertainty is how the effectiveness of alternative sediment controls will be evaluated. The SMCRA and Clean Water Act effluent limitations are technology-based standards dependent on the designation of any control structure as a point source. For example, if the alternative controls implemented at the mine discussed in box 8-B are considered point sources, they must meet the TSS limitation of 70 mg/l; otherwise they could have TSS concentrations measured in the tens of thousands and be in compliance with Wyoming regulatory program standards so long as the receiving water quality is not degraded.

In approving the experimental practice illustrated in box 8-B, OSM indicated that the effectiveness of the alternative controls will be evaluated in terms of whether they are at least as effective as sediment ponds. If this means achieving point-source effluent standards, obviously alternative practices will not be as effective as ponds. The operator's evaluation program for this experimental practice is designed, with State concurrence, to measure effectiveness in terms of nondegradation of water quality—i.e., whether the alternative controls will prevent additions to naturally occurring TSS concentrations. The alternative sediment control practices also will be evaluated in terms of minimizing land disturbance

Box 8-B.—An Experimental Practice for Alternative Sediment Control[1]

A surface coal mine in southwestern Wyoming requested an exemption to the use of sediment control ponds because the mine's large area and high drainage density would have required the construction of about 200 ponds, and because the region's ephemeral streams have naturally high sediment loads. The sedimentation ponds would be classified as point sources of pollution under the Clean Water Act. Therefore, they would be subject to stringent effluent limitations for pH, suspended solids, total iron, and total manganese. The natural sediment concentrations in the area range from 400 to 1 million mg/l—far in excess of the point source effluent standard of 70 mg/l.

Under the Wyoming regulatory program, an exemption from the use of sedimentation ponds can be granted if alternative sediment control measures are adequate to prevent mine drainage from degrading receiving waters. Although the operator's premining data and analyses indicated that such degradation would not occur, and DEQ granted the exemption, OSM required that the alternative sediment control measures be permitted as a formal experimental practice under SMCRA.

The objectives of the alternative sediment control plan at this mine are to protect water quality, conserve soil, and reduce mining costs. Other environmental advantages cited by the operator are the elimination of channel degradation below dams (from the discharge of unnaturally clear and therefore erosive water); reduction in land disturbance that would have been required for the construction of sediment ponds (estimated at over 400 acres); and mitigation of water quantity impacts on natural streamflows through elimination of impoundment storage, seepage, and evaporation.

In-stream flow criteria were established to provide a clear definition of stream water quality degradation. Though this plan deals with nonpoint source runoff exclusively, the operator used the NPDES point source parameters for iron, manganese, pH, and TSS a guide from which to select nonpoint source water quality parameters. Baseline surface water quality data showed that TSS was the only parameter in *natural* streamflow that consistently violated NPDES criteria. Therefore, the operator used TSS concentrations as the design parameter for the alternative sediment control program. After consultation with the regulatory authority, the operator designated the largest ephemeral stream in the area (to which all streams within the permit area are tributary) as the receiving stream. The receiving stream is not currently truncated by the pit, and changes in through-flowing water quality therefore can be observed at sites above and below the disturbed area. Alternative sediment control techniques will be used in all areas draining to these sites.

In order to apply the alternative control techniques in a rigorous manner to the disturbed areas, the operator developed a design method based on a standard computer simulation model (SEDIMOT II; see ch. 6) to simulate runoff from an area prior to the need for sediment control and with different sediment control techniques. The sizes and locations of the controls were evaluated to determine how best to reduce the sediment discharge to levels below the receiving stream water quality. Successive computer iterations were conducted and additional sediment controls added as necessary until the design TSS concentration (30,000 mg/l) was achieved. Control structures were added in the following order: rock check dams, contour interceptor ditches, contour berms, vegetative buffer strips, toe ditches, temporary barriers, and benches on stockpiles. For the nine areas modeled, four required no control measures to limit TSS concentrations to values less than or below the design value of 30,000 mg/l. Two watersheds required contour ditches and/or contour disking to meet target TSS concentrations.

In consultation with DEQ and OSM, the operator designed an extensive monitoring program to obtain site-specific and areawide hydrologic and sedimentologic data. These data will enable the operator to evaluate the effectiveness of the alternative techniques and to quantify the impacts of mine area drainage on water quality in the primary receiving stream. Data are collected on the receiving stream upstream of the disturbed area, on the drainage from the disturbed area, and on an undisturbed drainage that serves as a control watershed. In the event that runoff data show degradation of receiving water quality during a runoff event, the alternative sediment control program will be temporarily out-of-compliance. (The possibility of temporary noncompliance also exists for a sediment pond if the dam were to wash out, or if settled sediment were to be resuspended during discharge.) The company will identify the problem areas and take corrective measures to comply with regulatory standards.

The alternative sediment control plan was approved in July 1983. All alternative sediment control structures are required to be inspected monthly and following each rainstorm. Check dams are inspected individually; other measures are inspected visually by road tours. Repairs to any structure must be made as soon as machinery can be operated safely and effectively in the area. All such activity must be recorded in the daily mine log.

An unusually large number of runoff events have occurred since the plan was approved. While this has provided the opportunity to collect a substantial amount of monitoring data, it has also necessitated a lot of maintenance work, both on the monitoring equipment and on the control structures. The check dams in particular require sediment cleanout following runoff events, documenting their effectiveness but involving time and expense.

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[1] The material in this case study is from reference 6, case study 3.9

and changes to natural streamflow rates. If these additional criteria are applied to the performance of the control measures, then they may be more effective than sediment ponds in some cases. If this is demonstrated, the definition of best practicable control technology may have to be changed to recognize factors other than contributions of suspended solids.

SOIL HANDLING AND REVEGETATION[5]

The early State reclamation laws, followed by SMCRA and the Federal regulatory program, instituted requirements for topsoiling in the reclamation of surface mined lands. Soil handling and redressing ought to be an optimization process—too little soil or soil of poor quality and revegetation will be unsatisfactory; too much soil and money is wasted.

The results of long-term studies of the effects of different methods of soil handling on revegetation have indicated that stockpiling can adversely affect the success of revegetation efforts. Studies that compare revegetation with stored soil versus directly hauled soil indicate that storing soil for more than about 2 years at many sites significantly decreases the viability of seeds and microbiota. The direct haul or "live" soil-handling technique (see ch. 3) preserves the biologically active component of the soil and tends to encourage faster reestablishment of nutrient cycles, improving the establishment of planted and volunteer species and producing superior lifeform and species diversity within a relatively short time. The most recent monitoring data at one mine where the conditions for revegetation are among the most favorable in the study area indicate that the combination of biologically active direct haul soil plus other innovative soil handling techniques can produce revegetation on some areas that meets the SMCRA performance standards even without direct seeding or planting (see box 8-C, below). The efficacy of direct haul soil handling varies among regions and sites within regions, however.

The importance of maintaining a biologically active soil is not surprising when one considers that temperate-zone grassland and shrub-steppe ecosystems—those common in the study area—have substantially more biomass (i.e., living tissue) below ground than above ground. Furthermore, a good portion of the central ecosystem

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[5] Unless otherwise noted, the material in this section is adapted from references 4 and 5.

Photo credit: Jenifer Robison, OTA staff

The foreground shows a portion of a mine in northwestern Colorado that was revegetated 4 years previously with volunteer growth (no seeding or planting) using two-lift direct-haul soil handling and supplementing the topsoil with mulch produced onsite by shredding the premining vegetation.

processes (nutrient and energy cycling) are located below ground.

Because the direct haul technique eliminates the middle step in the process of stripping, stockpiling, and respreading soil, it can be less expensive, depending on haul distances, equipment, and other operational considerations. Direct haul also is advantageous for small mines that do not have room for topsoil stockpiles. The fortuitous coincidence of economic and biologic advantage has caused direct haul to be adopted to some degree by most Western surface coal mines that are beyond the first box cuts, and that were able to incorporate it in their operational mine planning. At some mines, the area ultimately treated by direct haul will be well over 50 percent. In other cases, however, mine logistics can prevent the use of direct haul over much of the disturbed area (e.g., in deep or multiple seam operations). In North Dakota, the ability to direct haul soil also is limited by the regulatory requirement to return soils to the original landowner. Where direct haul soil handling is not feasible, supplemental topdressing—application of a thin layer of freshly salvaged topsoil—could enhance volunteer growth and diversity and serve as a source of desirable microbiota.

A second soil handling method that recognizes the importance of reestablishing the natural horizon order within soil profiles, and also helps to maintain biological soil components in an active state, is the handling and replacement of the biologically most active surface soil layers, without dilution by underlying subsoil—"two lifts." Two lifts require that surface materials are kept seg-

Box 8-C: Innovative Soil Handling and Revegetation Techniques[1]

In northwestern Colorado, conditions for revegetation probably are more favorable than anywhere else in the five-State study region, and the development of vegetation cover and production on reclaimed land has been very rapid. Seeded areas 3 to 7 years old at one mine in this area have about 60 to 85 percent cover, compared to 43 to 82 percent cover on baseline (undisturbed) areas. Similarly, herbaceous production levels are about 660 to 8,900 lb/acre, compared to 890 to 8,900 lb/acre in baseline vegetation types. Because of the favorable environmental conditions for revegetation, one operator experimented with volunteer growth from a combination of two-lift direct-haul soil handling supplemented with mulch produced onsite by shredding preexisting vegetation. The soils are salvaged to 18 inches. If the 18 inches is all organic-rich horizon, the entire 18 inches is handled in one lift. If subsoil occurs within the 18-inch salvage depth, however, separate handling results in 10 inches of subsoil being covered with 8 inches of topsoil. A trial area using this combination was allowed to revegetate naturally (i.e., without seeding or planting); it supports about 75 percent cover and about 2,140 lb/acre herbaceous production after 4 years. Based on 3 years of monitoring data for this trial, the operator petitioned the regulatory authority to have the seeding requirement waived on areas receiving direct haul soil with live mulch, arguing that the presence of viable seeds and potentially regenerative roots in the soil leads to the establishment of plants better adapted to the site than are available in mixes of commercially available seed. The proposed practice will be approved as a field trial.

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[1] See case study CO-1 and related text in reference 5; case study J in reference 4.

regated from subsurface materials during stockpiling or direct haul operations, and redressed with topsoils over subsoils (see ch. 3). The surface soil, including the A horizon along with the upper B horizon, is the zone of maximum organic matter accumulation and microbiotic activity. The subsoil, consisting of the lower B horizon (if present) and the C horizon, contains far less organic matter, and can have a layer of calcium carbonate accumulation that reduces its value as a plant growth medium.

Two-lift soil handling is an especially important consideration in deep soils. As a result, it has been practiced and/or required in Montana and North Dakota for years, and is standard practice at many other Western mines with deep soils. When a soil suitable to depths as great as 60 inches is salvaged in a single lift, the relatively thin surface layer of maximum biological activity is buried or mixed with relatively sterile, albeit chemically and physically "suitable" subsoil. Roots, seeds, and beneficial microbiota, as well as the organic-rich surface material, are diluted or lost by burial. Surficial organic matter that could increase soil moisture capacity and gas exchange and decrease erodibility is diluted. Seeds and roots are distributed throughout a large soil volume, many buried too deeply to aid revegetation.

The combination of two lifts with direct hauling is especially advantageous for the reestablishment of rangeland diversity, and may be enhanced even further in some instances by the use of other soil treatments such as mulch derived from shredding native vegetation (see box 8-C). There are no formal research projects directly comparing two-lift direct-haul soil handling with other methods, but monitoring data from the mines in the study area that are using this combination should be available within a few years for comparison with those from mines in the same areas using other methods.

The results of recent research and innovation on soil handling and revegetation raise questions about whether soil handling is optimized under the current regulatory framework. SMCRA, as implemented in the Federal regulations, requires that topsoil, defined as A and E horizons (originally the A horizon), be redressed over spoil, and that subsoils be used only if the regulatory authority determines it to be necessary (11). The State programs in the study area (with the exception of Colorado), however, require the salvage of all "suitable" soil, including A, E, B, and C horizons. In some cases this requires salvage of soil down to depths of 60 inches or more. "Suitable" is defined by physical and chemical criteria (pH, salinity, sodium adsorption ratio, texture, and other parameters such as coarse fragments, lime, boron, and selenium). This salvage requirement aims at providing the most favorable medium for seed germination and plant growth—a medium similar to that in which the native plants grew originally. **Salvage of all suitable soil is appropriate in many situations; e.g., when undetected deleterious materials may occur in the spoil, where erosion is a concern, or where the moisture-holding capacity of the spoil is limited. But it is not appropriate in every case.**

First, as discussed above, the experiments with direct haul, two lifts, and other techniques (e.g., mulch produced onsite from native vegetation) all indicate that the biological and organic parameters of soil are at least as important in determining soil quality for revegetation—if not more important—than physical and chemical criteria. **Greater attention needs to be paid to the biological quality of soil in planning and implementing soil handling and revegetation.**

An additional consideration is soil depth. There has been very little research on the optimum depth of soil as a function of soil quality. Much of the work has been on the soil depth needed over problem spoils. Where such spoils are not a concern, one rationale for requiring the salvage of all suitable soil is that in arid and semiarid regions, where soil moisture is assumed to be the primary limiting plant growth factor, the moisture-holding capacity of the reclaimed soil will be maximized by maximizing soil thickness. Thus, if none of the physical or chemical criteria is limiting in soil handling, depth to bedrock is the usual limiting factor. Yet the surface layers of soils generally have better structure, aeration, lower resistance to root penetration, and infiltration capacity than subsoils. These favorable characteristics will be diluted by salvaging all suitable soil (including B and C horizons) in one lift.

Organic matter is primarily responsible for the development and maintenance of soil structure. An organically rich, thin soil layer with well-developed structure at the surface will have better infiltration than a thicker soil with less organic matter, and the moisture-holding capacity of a soil low in organic matter may not be better than the spoil. Because organic matter typically decreases with depth, salvaging subsoil will dilute the organic matter content of the reconstructed soil unless two-lift handling is practiced. Where surface soils are low in organic matter and the soil nutrient content does not greatly exceed that of the spoils, a minimal thickness may be as effective as a thicker one. **Because present baseline analyses in permit applications do not evaluate characteristics such as organic matter or moisture-holding capacity of either the reclaimed soils or recontoured spoils, current soil thickness requirements do not consider the optimum reclamation needs** (see box 8-D).

Direct-haul soil handling could conceivably outweigh considerations of soil quality or thickness, but existing regulations can discourage direct haul. For example, in some cases the regulatory requirement for approximate uniform topsoil thickness actually promotes stockpiling. With a direct haul system, redressed thickness would vary as the mine moved through areas in which the premining thickness varies naturally. Stockpiling, however, allows a uniform thickness to be replaced over a landscape that had variable soil thicknesses before mining. Regulations that require the salvage of all suitable soil undermine the effectiveness of the direct haul method (without two lifts) because the biologic component of the topsoil that produces many of the beneficial effects of direct haul is compromised under the requirement to salvage all suitable horizons.

SMCRA itself is sufficiently flexible to accommodate all of these considerations related to soil handling and revegetation, but the regulations in most States are not. Several of the regulatory authorities do allow nonuniform thickness on a case-by-case basis, however. **In future revisions of the regulatory programs, special attention should be paid to relating requirements for soil quality and depth to the proposed mining and reclamation methods and the supporting baseline analysis.**

Box 8-D.—Challenging the Requirement for 100 Percent Soil Salvage[1]

The permit application for a case study mine in Wyoming stated:

> . . . [although] topsoil salvage depth is often emphasized as the most important criterion in providing suitable and sufficient plant-growth material to meet the proposed postmining land use . . . two better criteria are suitable plant growth material and quality replacement depth.

The applicant conducted a laboratory and short-term greenhouse study to show that the optimal salvage plan for several of the deep soils of the site would be to salvage the A, B, and upper C horizons and leave the lower C horizons. The applicant maintained that the lower C was no different from the overburden and, in some subsoils with high lime, the overburden was better. The operator proposed to salvage A, B, and upper C materials to be redressed over the 48 inches of suitable top bench cover material. The regulatory authority felt the results of the applicant's research were inconclusive, and rejected this approach, stating:

> . . . [it] does not meet the requirements of all applicable rules and regulations. Although the C topsoil material in some of the soils is not as fertile as the A and B horizons, it is felt that the stripping of those suitable C materials will not appreciably reduce the quality of the replaced topsoil.

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[1] See case study E in reference 4.

REVEGETATION OF WOODY PLANTS[6]

Woody plants—trees, shrubs, and subshrubs[7]—occur in a variety of plant communities in the Western United States, including the woody draws of North Dakota, the shrub-steppe communities of Montana and Wyoming, the mountain shrub communities at higher elevations in most States, and the pinon pine-juniper and salt desert shrub types of the Southwest.[8] **Woody plants are ecologically important in the West as forage and cover for livestock and wildlife as well as for improving soil moisture and for protecting leafy herbaceous plant species from heavy grazing.**

"Cover" includes a number of habitat features, such as thermal cover (shade) on hot days; hiding cover for solitude and protection from predators; shelter from wind; and nesting, perching, and feeding sites for birds and many small mammals. The food value of shrubs includes the actual leaf, stem, and fruit tissues of the shrubs for herbivores, as well as the variety of insects they support that serve as prey for songbirds and small mammals, which in turn are prey for raptors and carnivores. In areas where the shrub overstory is relatively open and varied, the herbaceous understory usually is diverse and forage plentiful, but where dense stands of shrubs with little diversity are present (as in severely overgrazed areas), the understory usually is sparse and forage more limited. Shrubs are particularly valuable during winter because they are more nutritious than the above-ground portions of dormant herbaceous species and more available because they protrude above snow cover.

Cattle, and to a lesser extent sheep, prefer herbaceous vegetation to shrubs. Cattle are heavily oriented toward grazing, although they do consume the current year's growth on smaller shrubs (and especially subshrubs) during fall and spring. Sheep also are grazers, but they tend to prefer forbs (nongrass herbs) rather than grasses, and they make greater use of shrubs than cattle, especially during the fall and winter. This enables sheep to be kept on rangeland throughout the winter even at northern latitudes, and to forage successfully (along with goats) in herb-poor desert shrublands in the Southwest. Even so, the quality of sheep range, like that of cattle range, is more apt to be limited by a scarcity of palatable herbaceous species than by the lack of shrubs.

Although shrubs in high densities may decrease the range value for cattle and sheep, their presence improves habitat quality for a variety of wildlife species. The food value of big sagebrush is particularly important for pronghorn antelope and sage grouse, which are species of special concern in the West because of their recreational and economic value. These species utilize sagebrush throughout the year, but especially in winter when other food materials either are buried under the snow, or offer low nutritional value, palatability, or digestibility. During severe winters, these animals may be almost totally dependent on sagebrush. Sagebrush also is essential to all other aspects of the life history of sage grouse. Open areas surrounded by sagebrush serve as strutting grounds, and most nesting and brood rearing occurs under sagebrush (3). In mountain areas, sagebrush openings near aspen stands can be important for elk calf-rearing. Other shrubs of value to wildlife include four-wing saltbush, Gardner saltbush, bitter brush, shadscale, winterfat, chokecherry, service berry, and mountain mahogany.

Besides their value for forage and cover, woody plants are important for improving soil moisture and for protecting herbaceous species subject to heavy grazing. Soil moisture in shrubby communities is enhanced because the woody plants accumulate snow within their crowns and in their lees, especially in windy prairie habitats. Woody plants also reduce wind velocities and hence desiccation at the ground surface. Moreover, the shading effect during summer may lower ground temperatures, and thus evaporation rates from the ground surface, sufficiently to offset the moisture loss from evapotranspiration though the

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[6] Unless otherwise noted, the material in this section is adapted from references 1 and 5.

[7] Subshrubs are perennial plants that are woody at the base and are either of small stature or die back nearly to ground level (i.e., intermediate between a shrub and a forb) (5).

[8] For descriptions of these plant communities and their importance for wildlife and livestock, see references 1 and 5 in vol. 2.

Photo credit: Office of Surface Mining

Lands in the northern portion of the study region typically include tame pastureland interspersed with sagebrush and other shrubs, with trees at higher elevations.

leaves. Groups of herbaceous plants are protected from grazing animals because the animals are unable to reach grasses or forbs growing around the base of a shrub. The protected plants serve as an important seed source, particularly in situations where heavy grazing virtually eliminates seed sources in open areas between shrubs. In some combinations of slope and substrate, woody plants also may improve slope stability because their more massive root systems can anchor a greater volume of material than many herbaceous species.

Because of the ecological importance of woody plants in the West, the revegetation requirements in SMCRA are tied to the reestablishment of native woody plant species as well as other lifeforms (forbs and grasses) by land use category (see ch. 7, table 7-2).[9] In States without specific woody plant standards for particular land uses, shrub density standards usually are negotiated on a case-by-case basis, based on the premining density, the postmining land use, and/or practicality (see box 8-E, below). For the desert shrub communities of New Mexico, the negotiated figure for shrubs generally is 190 stems/acre, while in northwestern Colorado (where the conditions for revegetation are among the most favorable in the study region) it normally is 1,000 stems/acre. In North Dakota, woody plant density standards only address wooded draws because of the paucity of shrubs or trees in upland sites. Guidelines and success standards for replacement of woody

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[9] The SMCRA performance standards and standards for revegetation success are discussed in chs. 4 and 7.

Photo credit: Utah International Inc.

Pinon-juniper woodlands occur in the surface coal mining regions of the desert Southwest.

draw habitat currently are being developed based on research at one mine (see ch. 3, box 3-N). Pinon-juniper habitats in New Mexico also are relatively scarce, but regulatory personnel there are uncertain whether the technology exists to replace pinon-juniper after the rocky substrata supporting these species have been altered.

Wyoming is the only State so far to propose a formal woody plant density standard that is not tied directly to the baseline premining density. The Wyoming proposal states that 10 percent of the reclaimed surface should have shrub densities of at least one stem per square meter (4,050 stems/acre), and the remaining 90 percent of the area should have shrubs included in the seed mix, but no shrub density performance standards must be met. This proposed standard was under review by OSM at the time of this writing (see ch. 7, box 7-B).

The requirements for reestablishing woody plants raise two issues. First, in all States except Wyoming, the standards call for uniform postmining densities based on premining values. In areas where the premining density is relatively high (primarily Wyoming, Colorado, and New Mexico), however, there is little field evidence that high densities can be reestablished over an entire reclamation site during the 10-year liability period even with the most advanced shrub establishment technology (see below). Second, in many areas the requirement to restore sagebrush in its premining density directly conflicts with ranchers' and surface management agencies' postmining range management practices.

Achieving woody plant density performance standards has been an area of concern throughout the study region, and the technology of shrub reestablishment has been a major focus of research and innovation. In the first few years after SMCRA was passed, operators found it extremely difficult to establish woody plants from seeds, and emphasis was placed on live plants from containerized stock (tubelings), bareroot

Box 8-E.—Innovative Techniques for Enhancing Reestablishment of Woody Plants[1]

A mine in northwestern Colorado has instituted a variety of innovative revegetation techniques to enhance woody plant density and diversity in this mountainous region where shrubs are especially important to wildlife. The mine-site includes four major premining vegetation types: aspen, mountain shrub, sagebrush, and meadow. The pre- and postmining land uses are primarily livestock grazing and wildlife habitat. Mature native shrub clumps are transplanted on 1,300 foot centers using specially modified front-end loaders or scrapers. Antelope bitterbrush and true mountain mahogany are seeded between the transplanted clumps. In some areas, hard-to-establish shrubs are drill-seeded at an angle to more aggressive species. In addition, sites with woody plant cover were treated before topsoil removal with a tractor-mounted shredder that leaves a residue of finely chopped woody biomass on the soil surface. This native-vegetation mulch is incorporated into the topsoil before the soil is direct-hauled to a reclamation site, creating an additional source of woody plant material. Big game predation on young shrub growth in reclaimed areas is diverted to adjacent undisturbed areas where mature low-productivity shrub growth is crushed to stimulate sprouting of new growth attractive to browsers (see ch. 3). Monitoring data for this mine show a range of shrub density from 0.28 to 0.86 stems/m² on 3-year old seedings and as high as 1.02 stems/m² on 1-year old seedings (the negotiated shrub density standard is 0.25 stems/m²).

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[1] See case study mine CO-1 in reference 5.

Photo credit: Jenifer Robison, OTA staff

Shrub clumps transplanted directly to reclaimed areas with a specially modified front-end loader can establish islands of native shrubs and other species from which volunteers may radiate later in the liability period.

stock, and direct transplants from native stands in the mine area. However, trials in mines in New Mexico, Colorado, and Wyoming with containerized and bareroot stock have shown low survival rates and very high costs per surviving stem. Bareroot stock also is only available for a limited number of suitable species. Direct transplanting of shrub clumps at some mines (see box 8-E) can establish islands of native shrubs, soils, and accompanying herbaceous species from which volunteers may radiate, vegetatively or from seed, later in the liability period. This method is very expensive, however, and it probably is not capable of establishing required stem densities over an entire reclamation site.

Because of the availability of seed and the cost advantages of direct seeding, recent shrub establishment technology essentially has come full circle, and this method is now accepted as the major means of achieving the required woody plant density effectively and economically. Improvements in the success of direct seeding resulted from recognition of the ecological fact that most shrubs cannot tolerate vigorous herbaceous competition during their first few years. Successful shrub establishment usually requires the use of techniques that reduce interspecies competition, such as separation in space or time from the aggressive cool season grasses that are planted to control erosion and to support grazing (see ch. 3).

Other techniques that may help improve shrub establishment include direct-haul soil handling (see separate discussion of *Soil Handling and Revegetation*), wildlife control, using locally adapted seeds, and applying mulch produced by shredding of woody vegetation (see ch. 3). The latter has been used successfully at a mine in northwestern Colorado (see box 8-E; see also ch. 3, box 3-L). Areas treated by this wood residue technique have shown substantial woody plant regeneration by root sprouting, resulting in far greater densities than had been achieved previously by seeding. Moreover, this method allows more complete topsoil salvage (due to the soil that normally adheres to uprooted shrubs and is disposed of with them in the absence of this method), and after topsoil removal and replacement on the reclaimed surface, sufficient organic debris remains on the surface to function as a mulch. The technique is now being tried at a mine in northwestern New Mexico where the vegetation is sagebrush shrubland and pinon-juniper forest, but results of that trial were not available at the time of this writing.

The results at the mine depicted in box 8-E suggest that shrub densities of one stem per square meter (4,050 stems/acre) can be realized at some mines in very favorable revegetation environments within the early part of the liability period using direct seeding and one of the various methods for reducing competition (see ch. 3). Monitoring data available from mines in less favorable environments for shrub reestablishment and using other technologies (e.g., live transplants) have resulted in lower shrub densities than those at the mine in box 8-E—in the range of 0.05 to 0.15 stems/square meter.

Fewer data are available concerning shrub establishment in the sagebrush-steppe ecosystems of the northern part of the study area. In the past, operators have found it difficult to establish shrubs other than fourwing saltbush in the Powder River basin of Wyoming, with a big sagebrush being especially difficult. The most recent data suggest that the prospects for shrub establishment may be improving as operators invest more effort in special measures. However, the ability to meet Wyoming's proposed standard of one stem per square meter on 10 percent of the area may depend on whether fringed sage and Gardener saltbush are counted as shrubs for density purposes.

The abundance of woody plants on Western rangeland has long been a source of aggravation to ranchers, who would prefer that postmining landscapes have fewer woody plants than before to improve grazing for cattle and sheep. As a result, ranchers have undertaken large-scale programs to thin or kill woody species—primarily sagebrush, but also Gambel's oak, and pinon pine and juniper—on rangelands, frequently with financial or physical support under rangeland management programs conducted by the Bureau of Land Management (BLM). Rangeland management may be accomplished by chemical means (spraying with a broadleaf herbicide), mechanical means (root-plowing or chaining), or burning. Such management generally reduces the wildlife habitat value of the land, can reduce the soil's ability to retain moisture, and can exacerbate the effects of overgrazing because the shrubs are no longer available to protect herbaceous species.

The issue of postmining versus premining sagebrush densities is further complicated by the widespread belief that present premining densities are greater than "natural" levels because of historical grazing pressure. Thus, range managers and ranchers often feel that mine reclamation programs should deemphasize sagebrush because high densities decrease the value of the land for livestock and are not "natural" for the region. While it is true that very high sagebrush densities may result from overgrazing (through selective removal of the forbs and grasses with which sagebrush seedlings must compete for moisture, nutrients, light, and space), their presence or even dominance in certain regions and on certain sites is sometimes related to other factors.

While mine operators and regulatory personnel recognize the ecological importance of woody plants, they consider it senseless that so much effort and expense is put into the reestablishment of premining sagebrush density when the postmining landowner or surface manager may negate those efforts through range management programs. This conflict is exacerbated because, while big sagebrush is the single most widespread shrub in the study area, it also is among the most difficult to reestablish.

For the most part, this conflict can be traced to the lack of specificity in designation of the postmining land use (see separate discussion in this chapter), and to inadequate coordination among Federal and State regulatory authorities and land management agencies. The options discussed in the next section for defining postmining land uses more carefully also could help mitigate the conflict between surface mine revegetation and rangeland management.

In addition, many State regulatory and mining industry personnel feel that lower woody plant densities, if accomplished as groupings based on premining habitat mapping, provide wildlife habitat as valuable overall as high uniform premining levels. In this context, rangeland management programs also can benefit wildlife if done selectively. For example, thinning big sagebrush to increase herbaceous production can improve the forage for pronghorn antelope as long as shrubs remain available in critical winter browse areas and are not totally removed from summer range. Similarly, thinning dense oakbrush can greatly improve the forage value for elk, which primarily are grazers, by increasing herbaceous production. Although deer mainly are browsers and are heavily dependent on shrubs throughout much of the year, thinning oakbrush and pinon-juniper also can be beneficial for deer because it stimulates tender young shoots that are more nutritious, palatable, and easily reached. For both deer and elk, however, thinning must be done in relatively small blocks so that adequate densities of tall brush and trees remain nearby for the requisite thermal and hiding cover.

Photo credit: Jenifer Robison, OTA staff

Uniform high premining shrub density may be difficult to reestablish on mined land within the liability period. Lower overall woody plant density accomplished in high density groupings may still provide valuable wildlife habitat while preserving the range value for cattle and sheep.

POSTMINING LAND USE

The postmining land use is defined during permitting of a surface coal mining operation. Under the Federal regulations, "land use" means specific uses or management-related activities, rather than the vegetation or cover of the land. Multiple land uses may be identified when joint or seasonal uses occur. Native rangeland is the most extensive premining land use in the study area (see ch. 3). The regulations define "native rangeland" as land on which the natural potential (climax) vegetation is principally native grasses, forbs, and shrubs valuable for forage. This includes natural grasslands and savannahs, as well as juniper savannahs and other brushlands. Except for thinning shrubs (see discussion of *Woody Plant Revegetation*, above), management of native rangeland primarily involves regulating the intensity of grazing and season of use (10).

Other common land uses in the study area (as defined in the Federal regulations) are:

- **Cropland:** land used for the production of adapted crops for harvest, alone or in rotation with grasses and legumes, including row crops, small grain crops, hay crops, nursery crops, orchard crops, and other similar crops.
- **Pastureland or land occasionally cut for hay:** land used primarily for the long-term production of adapted domesticated forage plants to be grazed by livestock or occasionally cut and cured for livestock feed.
- **Grazingland:** land used for grasslands and

forest lands where the indigenous vegetation is actively managed for grazing, browsing, or occasional hay production.

- **Fish and wildlife habitat:** land dedicated wholly or partially to the production, protection, or management of fish or wildlife species (10).

In the West, the postmining land uses usually are the same as the premining uses, although some changes can occur. Where the surface is privately owned, for example, the postmining land use generally is consistent with the surface owner's preference. Thus, at a mine in North Dakota, the postmining land use will convert most of the existing rangeland to cropland at the stated request of the surface owners (see box 8-G, below).[10]

OTA identified three issues related to the designation and implementation of postmining land uses: the lack of specificity in describing postmining land uses, implementation and management of the postmining land use after bond release, and the effects of the postmining land use designation on the difficulty of reclamation.

Designating the Postmining Land Use

As discussed in chapter 4, SMCRA requires that surface mined land be restored to a condition capable of supporting the uses which it was capable of supporting prior to any mining, or higher or better uses of which there is reasonable likelihood (13). SMCRA and the regulatory programs require detailed characterizations of the premining and postmining land uses in the permit application and reclamation plan. The permit application package must contain a statement of the condition, capability,[11] and productivity[12] of the land within the proposed permit area, including: 1) a map and supporting narrative of the uses of the land at the time of the filing of the application and, if the premining use was changed within 5 years before the anticipated date of beginning mining, the historic use; and 2) a narrative of land capability and productivity, which analyzes the land use description relative to other required environmental resources information (climatological, vegetation, fish and wildlife resources, soil resources), as well as to the land's premining capability and productivity (15). The reclamation plan also must describe the use that is proposed to be made of the land following reclamation, how that use is to be achieved, and the necessary support activities that may be needed to achieve it. Where the postmining land use is rangeland or grazing, the operator must provide details on the management plans to be implemented (16).

Some of the State regulatory programs require an even greater degree of specificity in describing pre- or postmining land uses. In Wyoming, for example, the regulations require a permit applicant to describe and rank the previous uses of affected lands on an individual basis according to the overall economic or social value of the land use to the area or local community (9).

Despite the requirements for detailed descriptions of the pre- and postmining land uses, and quantification of land capability and productivity, the characterization of these uses is extremely perfunctory. A number of the surface mining permits and reclamation plans reviewed for this assessment contained land use discussions with little more information than the statement, "The premining land use is grazing and the postmining land use is grazing." In some cases, this lack of specificity can be attributed to inadequate baseline characterization by the permit applicant. In others, it is the fault of the Federal surface management agency, which is required to determine, or at least consent to, the postmining land use on Federal lands (17).

This lack of specificity and quantification can adversely affect postmining vegetative and landscape diversity (see separate discussions in this chapter), the implementation of surface owners' or management agencies' land use recommen-

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[10] See case study mine A in reference 4.

[11] For the purposes of BLM land management, "capability" means the ability or potential of a unit of land to produce resources, supply goods and services, or allow resource uses under a set of management practices at a given level of management intensity without permanently impairing the resource involved. Capability depends on a fixed set of conditions that are relatively stable over time, including but not limited to, climate, slope, landform, soils, and geology (14).

[12] Productivity is determined by yield data or estimates for similar sites based on current data from the U.S. Department of Agriculture, State agricultural universities, or appropriate State natural resource or agricultural agencies (15).

dations, and the difficulty and cost of reclamation. Moreover, at mines where reclaimability is an issue during permitting, much more rigorous approaches to characterizing premining land uses, and to predicting the capability and productivity of the reclaimed surface, are necessary to demonstrate reclaimability (4).

The principal option for resolving this problem is for the regulatory authorities to enforce more strictly the permit application and reclamation plan requirements for pre- and postmining land use characterization. For privately owned lands, the land use description and the quantification of capability and productivity must remain the responsibility of the permit applicant, with the cooperation and concurrence of the landowner. The U.S. Forest Service (USFS) has developed a system for predicting potential land capability classes on reclaimed surfaces, which could be used for such quantification. The acres of land in each capability class in the premine condition could be compared to the predicted acres in the postmining condition to determine if the land capability would be maintained (4).

On public lands, the applicable land use and activity plans prepared by the surface management agency should provide the basis for quantitative characterizations of pre- and postmining land uses.[13] The surface management agency prepares a resource management plan or other land use planning document as the first step in analyzing Federal lands for their suitability for a variety of uses, including coal resource development. This document is then supplemented by BLM during activity planning for a coal lease sale with detailed site-specific analyses for each proposed lease tract. The information in these plans and analyses should be sufficiently detailed to meet the requirements in SMCRA and the regulatory programs for the quantitative characterization of pre- and postmining land uses, capability, and productivity.

BLM and USFS currently are in the process of preparing land use plans that meet the requirements of the Federal Land Policy and Management Act of 1976. Until these documents are completed, **Federal surface management agencies should ensure, during interagency review of permit applications and reclamation plans, that careful attention is paid to the quantitative characterization of pre- and postmining land uses, productivity, and capabilities.**

Implementation and Management of the Postmining Land Use

Implementation and management of the postmining land use after bond release raises issues about changes in land use, conflicts among land uses, and the long-term success of reclamation. If the proposed postmining land use is different from the premining or historical land use, the regulatory authority must formally approve a "change to an alternative land use" (10). After consultation with the landowner or the surface management agency, the regulatory authority may approve a higher or better use as the alternative if the proposed use meets the following criteria: 1) there is a reasonable likelihood for achievement of the use; 2) the use does not present any actual or probable hazard to public health or safety or threat of water diminution or pollution; and 3) the use will not be impractical or unreasonable, be inconsistent with applicable land use policies or plans, involve unreasonable delay in implementation, or cause or contribute to any violation of Federal, State, or local law.

Changes to alternative land uses can be beneficial for the capability and productivity of the land. At a surface mine in the Colorado portion of the San Juan River Region, for example, the operator will attempt to change part of the permit area to a higher or better use. At this mine, the premining land uses were rangeland, wildlife habitat, and some privately owned dryland pasture. About 20 acres of rangeland will be reclaimed to pasture to increase the ability of the land to support livestock husbandry.[14] However, such changes also can make reclamation more difficult and costly (see below).

At other mines, conflicts arise between land uses—particularly between agricultural uses and wildlife habitat. In these situations, restoration of wildlife habitat features is often in conflict with the management objectives of the landowners, who usually are farmers or ranchers who desire all land returned to cropland, pastureland, or grazingland. This conflict is most evident where reclamation standards for wildlife habitat (e.g., woody plant density standards and overall vegetative diversity) are more difficult to meet than those for other land uses, such as pastureland. It is especially a concern in areas such as North Dakota, where natural habitat is very limited in areal extent and is "shrinking" each year due to water developments, urban expansion, and agricultural expansion. At a mine in North Dakota that is converting most of the premining rangeland to cropland at the request of the surface owners, this conflict is being resolved by the replacement of premining wildlife habitat on an acre-for-acre basis after mining.[15]

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[13] See the discussion of the Federal coal leasing program in ch. 4.

[14] See case study mine K in reference 4.

There are no regulatory mechanisms to ensure that the surface owner will not convert lands reclaimed for one use (e.g., wildlife habitat) to other uses after bond release. As with the conflict over sagebrush reestablishment discussed in the previous section, operators consider it senseless to restore wildlife habitat and native rangeland at great expense when the surface owner will convert the land to tame pasture or other uses after bond release.

Similarly, **although the use itself may not change, even the best reclamation can be negated quickly by postmining land management decisions or techniques.** For example, much of the land in the West is used for grazing and, historically, there have been problems with overgrazing adversely affecting vegetative density and diversity. While many reclaimed surface mine lands are required to graze for a specified period of time prior to bond release, the operator can control the number and type of livestock in such grazing tests. After bond release, however, grazing pressures on reclaimed lands can increase significantly. Similarly, the mix of woody plant species for revegetation may be selected to favor particular wildlife species, but postmining management practices to enhance pastureland uses can reduce the number of shrubs beneficial to those species and the overall vegetational diversity.

One solution to conflicting land uses, postmining land use conversion, or improper management is careful design for the return of land uses that minimize post-reclamation conflicts (see box 8-F, and the discussion of landscape diversity, below). Greater specificity in describing the postmining land use (e.g., number and type of livestock that will be grazed after bond release) would aid in this effort.

Effects on Reclamation

Specification and implementation of the postmining land use are extremely important for the reclamation plan and for the evaluation of the success of reclamation. Many of the reclamation plan requirements, performance standards, and bond release criteria in SMCRA and the regulatory programs are tied directly to the postmining land use. Two of the general objectives of the performance standards are the prompt reclama-

Box 8-F.—Designing Reclamation To Minimize Postmining Land Use Conflicts[1]

At a surface mine in Northwest Colorado, the mine personnel believe that the postmining land use governs how and where reclamation practices are to be implemented. Accordingly, they are implementing an optimal land use design in which premining land uses are reestablished on the postmining topography according to slope and elevation such that the best management practices can be applied for each land use. Lower elevational land with less than 12-percent slopes will be returned to the premining use of agriculture. Land with greater than 12-percent slopes that is not suitable for agriculture will be reclaimed to grazingland. Land at higher elevations, as well as rough breaks and drainages, will be reclaimed to wildlife habitat. No attempt was made to reestablish uses in the areal configuration in which they existed prior to disturbance. This differs from more typical approaches where land unit for land unit is returned to its premining use.

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[1] See case study mine F in reference 1.

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[15] See case study mine A in reference 1.

tion of all affected areas to conditions that are capable of supporting the premining land uses or higher or better uses, and revegetation that achieves a prompt vegetative cover and recovery of productivity levels compatible with approved land uses (18). The specific performance standards for backfilling and grading, topsoil and subsoil redistribution, revegetation, protection of the hydrologic balance, and protection of fish and wildlife also are tied to support of or consistency with the approved postmining land use (19-23). Furthermore, the regulatory standards for determining the success of revegetation vary according to land use category (grazingland, pastureland, cropland, wildlife habitat, rangeland), and specify that revegetation shall be judged on its effectiveness for the approved postmining land use (16).

This variability in the regulatory standards directly affects the difficulty and cost of reclamation because there are more stringent reclamation requirements for some land use categories. Except in North Dakota, postmining land uses generally are designated as native rangeland and wildlife habitat rather than improved grazingland or tame pastureland. As a result, these lands are subject to the full requirements for the establishment of native species; vegetative diversity, permanence, cover, seasonality, and self-regeneration; and woody plant density and diversity. For land reclaimed to cropland, there are no requirements in the study area States for vegetative diversity, permanence, cover, seasonality, and self-regeneration, but the soil reconstruction requirements may be more stringent (see box 8-G) (5).

More careful attention to description of postmining land uses, and to considerations related to landscape diversity, could, in the long term, reduce the difficulty and cost of reclamation in that the stricter requirements for particular uses would be limited to specified areas rather than applied to an entire reclamation site. While mine operators and reclamation specialists may experience initial difficulties and costs in adjusting their planning for and implementation of such an approach, the long-term benefits for the ease and success of reclamation could be great.

Box 8-G.—The Effects of Postmining Land Use on the Cost of Reclamation

At a mine in North Dakota, the premining land use was mostly for dryland wheat production, with about 10 percent of the permit area being used as rangeland. Although areas in rangeland have some limiting soil factors (typically shallow depth) that inhibit their use as cropland, the postmining land use characterization indicates that most of these rangelands will be converted to cropland at the stated request of the surface owners. As a result, the operator will be subject to the more stringent cropland vegetative productivity standards, which can be more costly to achieve than the rangeland standards if the soils are not suited to growing crops.[1]

At a mine in the Eastern Powder River basin in Wyoming, the premining land uses were 76 percent native grazinglands and improved pasture, 16 percent haylands, and 7 percent croplands. The premine croplands were used for wheat, oats, and barley. The permit application stated that "low crop yields and high operating costs make tillage agriculture a break-even or net loss operation in most years." Therefore, land uses at the site were ranked in value (as required in Wyoming) as: 1) hayland (improved pasture), 2) grazingland, 3) cropland, 4) water resources, and 5) wildlife habitat. Despite these rankings, most of the site will be reclaimed to grazingland based on the premining survey of surface owner preferences. Croplands will be reclaimed despite the marginal yields, and the operator will have to meet the yield standards for bond release. Some grasslands will be reclaimed to shrublands to maximize wildlife habitat, and will be subject to the woody plant density and diversity standards. Haylands will not be restored.[2]

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[1] See case study mine A in reference 4.
[2] See case study mine E in reference 4.

LANDSCAPE DIVERSITY

In surface mine reclamation, the term "diversity" traditionally has been used in the context of vegetative diversity in lifeforms, species, or seasonality. The most recent reclamation and related research indicates, however, that a broader meaning of "diversity," one that encompasses the entire landscape, may be important to the quality of reclamation. **This concept, known as landscape or ecosystem diversity, recognizes the mosaic nature of Western landscapes that results from localized differences in the physical environment, plant communities, wildlife populations, and land uses.** The five-State study area has a wide range of localized environments, including native prairie, badlands, wetlands, woody draws, broadleaf tree and shrub communities, shrub-steppe communities, ponderosa pine woodlands, rimrock or escarpments, riparian areas, mountain shrub communities, meadow communities, aspen woodlands, pinon-juniper communities, and desert.[16] Even some abandoned mined lands in the West have become prime wildlife habitats because of their diverse landscape relative to the surrounding area. In North Dakota, some orphan mines are protected State wildlife areas.

Localized environments on mine sites are altered or lost during mining, but with special attention to landscape diversity in planning reclamation, many of these features could be restored. This subject has received little attention, however, at either the State or Federal level, although requirements for specific mines have been established on a case-by-case basis, primarily in relation to reestablished plant communities. The restoration of ponderosa pine woodlands in Montana, woody draws in Montana and North Dakota, and wetlands in North Dakota are examples of reclamation that attempts to preserve landscape diversity. The proposed woody plant diversity requirement in Wyoming for dense shrub patches on 10 percent of the mined area clearly addresses this issue (see separate discussion in this chapter). Informal approaches to woody plant density standards in Colorado also have begun to include mosaic plantings of shrubs to enhance community diversity (5).

The importance of physical and vegetational diversity of an area has been recognized for some time in relation to the number of wildlife and livestock species and individuals that it can support. A well-established diverse community of cool and warm season grasses, forbs, and shrubs on a varied physical landscape provides vastly more feeding and nesting sites, thermal and hiding cover, and food items than a monoculture. Additionally, different food items become available throughout the seasons of activity so that there is less of a "feast or famine" effect. Lifeform and species diversity in vegetation also may enhance long-term survival of a plant community, because the various plant species are able to tolerate slightly different combinations of environmental factors. The various reproductive strategies and delicate competitive balance within a diverse plant community would enable some species to quickly fill any void created by the decline or demise of other species. As a result, the soil and wildlife resources would be buffered from an environmental stress such as overgrazing or drought (5).

As reclamation experience is gained in the West, an understanding of the complex interrelationships among all of the physical aspects of the environment is leading to an interdisciplinary approach to reclamation that recognizes the importance of diversity in more than the vegetation. The shift to such an approach has encompassed the design of everything from the overburden in its relation to water quality, to restored surface drainage systems, to the physical and vegetative features of the postmining landscape:

- The term "engineered cast overburden" was coined by researchers in North Dakota to refer to an approach to control of postmining groundwater chemistry that combines geologic and soil mapping, geochemical and geohydrological studies, and development of a three-dimensional materials framework, with a thorough understanding of the form and internal structure of material deposited by various types of mining equipment and techniques, to determine how best to obtain optimum physical and chemical characteristics at desired locations within the cast overburden (see ch. 6, box 6-H) (6).

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[16] These localized environments and their ecological importance are described in detail in the technical reports in vol. 2.

- The design of restored surface drainage systems is beginning to combine the concepts of quantitative geomorphology, rainfall-runoff hydrology, and detailed hydraulic analyses with appropriate revegetation to enhance both erosional stability and the wildlife value of riparian areas (6).
- Other research in North Dakota suggests that reconstructing sites with topography that catches and retains moisture is very important in cropland productivity and in reestablishing deciduous shrub and tree communities. At one mine in that State, a small field of prime farmland was placed on a concave landscape position in the design of the postmining surface to maximize water runon and snow accumulation (4).
- Many wildlife habitat requirements relate to the physical features of an area in addition to its vegetational components. Topographic diversity provided by rock outcrops, minor variations in slope/aspect, and the juxtaposition of different plant species and types create a variety of ecological niches important to many species of wildlife (1).

Photo credit: Jenifer Robison, OTA staff

The topographic diversity provided by rock outcrops, minor variations in slope/aspect, and the juxtaposition of different plant types on undisturbed lands (left side of photo) create ecological niches important to wildlife that may be lost if the surface is homogenized during reclamation (right side).

Adoption of a landscape diversity approach to surface mine reclamation involves trade-offs between the cost and/or difficulty of achieving diversity versus the potential long-term benefits for the quality of reclamation. Moreover, some regulatory requirements (e.g., highwall reduction, uniform topsoil thickness) may actually discourage innovative approaches to diversity. These requirements are directed at pre-SMCRA abuses, but do not incorporate the more recent reclamation experience on the benefits of diversity. Permit applicants will have to include the cost of obtaining a site-specific variance from such requirements in their overall assessment of the costs and benefits of achieving diversity.

Reclamation design at some mines has been kept as simple as possible to minimize costs and conflicts with conventional mining methods. Promoting an interdisciplinary approach to design and implementation of landscape diversity would require some additional effort, and thus cost, in premining baseline studies, in specification and design of the postmining land use, in implementing the reclamation design, and in developing criteria for evaluating the success of reclamation. Moreover, obtaining a permit for a design that conflicts with regulatory program requirements may require approval of a site-specific variance or an alternative reclamation technique. These are expensive and time-consuming to obtain, especially given the risk of disapproval and subsequent redesign and resubmission of the permit application package. On the other hand, once approaches to landscape diversity become accepted, they could provide cost savings (e.g., in soil handling, seeding, and grading), as well as benefits for the quality, and perhaps the long-term success, of reclamation.

The legislative and regulatory requirements that are most often cited as deterrents to reclamation designs that incorporate diverse landscape features are those related to restoration of approximate original contour (AOC) and uniform topsoil depth. **The requirement for full restoration of AOC was intended to prevent large discrepancies between premining and postmining topography, but, in the West, typically has resulted in gently undulating land with little topographic variety. This has substantially lim-**

Photo credit: Jenifer Robison, OTA staff

This surface mined area was reclaimed pre-SMCRA. Portions of highwalls were retained with ponds at their base to provide a source of water for range animals and wildlife in this extremely arid area.

ited the potential for vegetative and wildlife diversity. A full consideration of geomorphology in reclamation design would emphasize not only restoration of AOC, but also the postmining topography's consistency with the hydrologic characteristics of the reconstructed soils, the revegetation communities, the reconstructed drainage systems, and the proposed postmining land use, as well as its compatibility with the geomorphology of the contiguous areas (4).

There are some landforms that always will be impossible to restore to their premining condition. For example, hogback ridges are supported by resistant strata that would be removed during mining, precluding ~~their~~ reestablishment on the reclaimed surface. Similarly, badlands—bare outcrops of vari-colored shales that compose highly dissected mesas, buttes, pillars, and rock tables with high drainage density and little soil—cannot be re-created because mining removes the thin resistant strata of sandstone and siltstone that act as ledge- and pedestal-formers and on which the badland topography has formed by erosion (4). Where these features are ecologically unique, they could be preserved through measures such as unsuitability designations (see ch. 4).

In other cases, however, the postmining topography can be designed to mimic premining features such as rimrock and "microsites." Rimrock or escarpments are physical habitat features that can occur in a variety of vegetation communities, and serve as nesting or denning sites for many species of mammals, birds, and reptiles. Golden eagles, red-tailed hawks, great-horned owls, and prairie falcons commonly nest on ledges or in cavities in rimrock and, in many areas of the West, suitable cliff-nesting habitat is a limiting factor to these raptor populations. Rimrock also serves as protective cover for a wide range of animal species during winter storms, and it col-

Photo credit: Jenifer Robison, OTA staff

In this post-SMCRA mined area, the highwall was reduced (background), leaving gently-undulating land with little topographic variety.

lects moisture that promotes a greater variety of shrubs or trees than are found in adjacent communities (1).

Attempts have been made at many mines to mimic rimrock in the postmining landscape with rock piles, but these usually bear little physical resemblance to the original features, and do not provide as much topographic, vegetative, or habitat diversity as the rimrock or escarpments that were removed during mining. Alternatively, portions of highwalls with appropriate aspect and ledges or cavities could be left after reclamation to restore valuable nesting habitat that otherwise would be lost because of mining and reclamation. However, the AOC provisions of

Photo credit: Utah International Inc.

Badlands cannot be re-created because mining removes the siltstone and sandstone strata on which the badland topography formed through erosion.

SMCRA require that all highwalls be eliminated. While leaving an unreduced highwall portion clearly would provide cost savings in reclamation, the cost and difficulty of obtaining regulatory approval for an experimental practice or alternative reclamation technique for highwall retention generally is a serious deterrent. This deterrent has been overcome in a few instances in order to create artificial cliffs or bluff extensions that come closer to simulating the original features than rockpiles and that aid in the retention of additional surface moisture near the highwall base (box 8-H; see also ch. 3, box 3-O; and ch. 9, box 9-A).

Small premining surface features (or "microsites") are another aspect of landscape diversity that may be foreclosed by a lack of understanding about their importance, or by the difficulty and cost of their design, permitting, and restoration. Minor depressions, drainages, and hummocks that exhibit different slope/aspect combinations and are dependent on varying topsoil depths and soil structure characteristics not only provide topographic diversity, but also encourage vegetative diversity vital for the reestablishment of a variety of wildlife. SMCRA and the Federal regulatory program allow small depressions on the postmining landscape if they are needed in order to retain moisture, create and enhance wildlife habitat, or assist revegetation. Some forms of microsites are difficult to re-create, however, because they are dependent on particular hydrologic, soil, and overburden characteristics that are very expensive to duplicate with available mining and reclamation equipment.

An internal drainage including a playa has been approved for one mine in Wyoming.[17] The heavy clay soils typical of such features will be special-handled and returned to the playa. This will necessitate precise timing to catch the limited range of appropriate soil moisture content to avoid massive clod or block development and subsequent difficulty in developing a suitable seedbed.[18]

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[17] A playa is the flat-floored bottom of an undrained desert basin that becomes at times a shallow lake.

[18] See Case Study Mine WY-6 in reference 5.

Box 8-H.—Retaining a Highwall Portion To Simulate a Bluff Removed by Mining[1]

The permit application for this surface mine in the Montana portion of the Eastern Powder River basin contains an innovative postmining topography that raises questions of AOC, erosion control, uniform topsoil thickness, maximization of the coal resource, alternative reclamation, and experimental practices. It is referred to as the "bluff extension alternative."

The coal being mined extends under some large bluffs, which are capped by a massive and thick (greater than 100 feet) sandstone bed that has eroded into irregular cliffs. Mining into the bluffs and subsequently reducing the highwalls to a maximum 5:1 slope would require 1.5 million cubic yards of overburden to be cut back from the previously undisturbed bluff tops, essentially removing the original topography. This alternative was not considered economically viable by the applicant. On the other hand, not mining into the bluffs would mean the additional coal would not have been recovered. Therefore, the operator proposed to extend the mine pits into the deeper overburden on the footslopes of the bluffs, but to retain 50 to 100 feet of the final pit highwalls adjoining existing undisturbed competent sandstone. Below these highwalls, the final pit will be backfilled to the flattest practical slope. The final highwall blast will be designed to maintain competence, but also to maximize the roughness of the highwall for wildlife habitat. Rock rubble will be placed at the base of the highwall to improve wildlife habitat.

The plan was accepted by the Montana regulatory authority as an alternative reclamation plan because it optimizes use of the coal resource and achieves AOC, although it varies from the requirements to reduce all highwalls and redress topsoil. The plan minimizes erosion because the steep, short highwalls are capped by the resistant sandstone and the slopes at the bottom of the highwalls will be as gentle as possible. Reducing the highwalls to 5:1 would produce long slopes that would be much more erodible.

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[1] See Case Study Mine C in reference 4.

Similarly, in North Dakota, it is common for the premine surface to lack a well-integrated drainage system, and to have many closed depressions (prairie potholes) typical of glaciated topography. The potholes are wetlands that are important to wildlife, and one mine is undertaking an extensive research project to determine whether prairie potholes can be reconstructed and reclaimed (see ch. 3, box 3-G).

At a mine in Montana, restoration of a coulee bottom is being undertaken in response to a permit stipulation.[19] The moderately steep, concave sides with north to east aspects will be protected with a heavy straw mulch (5 to 7 ton/acre) applied after topsoil application and deep ripping of the side slopes, and then planted with woody species.[20]

Requirements for uniform topsoil depth over the regraded surface further homogenize site conditions and limit the potential for vegetative community diversity. Federal regulations require that topsoil be redressed in a uniform thickness consistent with the postmining land use. The Montana legislation has a provision for special reconstruction of soils using nonuniform depths, but the other States routinely require uniform thickness on each reclaimed area unless specifically exempted due to site-specific conditions (4). This requirement does not recognize the naturally occurring variation in soil depth that contributes to landscape diversity and strongly influences long-term plant community structure. At some sites, variations in topsoil depth, even to the point of no topsoil in areas intended for reestablishment of some types of woody plant species, may be more appropriate (see box 8-I). Moreover, because of the natural variability in soil depth, restoring uniform thicknesses can increase haul distances and thus costs, and can interfere with the ability to direct haul topsoil.

Box 8-I.—Reestablishing Sandstone Strata[1]

This small surface mine in southwestern Colorado is mining coal under a surface originally covered by massive sandstone vegetated by pinon pine, juniper, tall shrubs, and scattered patches of warm season grasses located in crevices and on small terraces. After the coal is removed, the exposed surface will be another massive sandstone stratum. The reclamation plan calls for blasting shelves into this sandstone, placing fine material on these shelves and planting to trees, shrubs, and grasses.

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[1] See case study mine CO-4 in reference 5.

There are several other arguments against uniform thickness related to erosion control and the moisture-holding capacity of soils. One operator suggested thicker soils on ridges and thinner soils in swales in relatively high precipitation areas of the West; the landscape would be designed to forestall the effects of soil erosion on ridges. Another suggested the opposite in desert areas, where topsoil is at a premium and premine vegetation density is extremely low. In the desert, putting a very thin layer of topsoil on uplands and using most of the soil in the swales would produce deep soil profiles capable of storing moisture from runon and supporting better vegetation cover, while a uniform thickness would result in soils unnecessarily deep on the uplands and too thin in the swales. Research in North Dakota suggests that, to produce an optimum landscape position for dryland wheat production, thinner soils ought to be placed in concave positions, which support higher production regardless of soil thickness, with thicker soils redressed on convex surfaces to maximize moisture-holding capacity (4).

A number of mines are redressing nonuniform topsoil thicknesses to replicate premining conditions, facilitate direct haul of topsoil, and promote vegetative diversity:

- **New Mexico:** At this mine, topsoil and subsoil will be redressed either in two 4-inch lifts to a depth of 8 inches over coarse-textured, benign spoil (sodium adsorption ratio—SAR—of less than 20 and a clay content of less than 28 percent), or to a depth of 18 inches in two lifts of 4 and 14 inches respectively over less favorable spoils (most of the mine), where SARs average 53 (4).
- **Wyoming:** The thickness of topsoil redress-

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[19] A coulee is a steep-sided drainageway that normally is dry by late summer.

[20] See Case Study Mine MT-1 in reference 5.

ing at this operation will range from 2.4 to 5.1 feet, depending on premining thickness, because of the long haulage distances that would be necessary to even out differences that occur naturally over the site (4).

- **Wyoming:** The topsoil handling plan for this mine calls for uniform distribution by mining block, but nonuniform distribution across the permit area. Redressed topsoil depth will range from 1 to 23 inches (4).
- **Wyoming:** This operator proposes to put 6 inches on the ridges and 36 inches in the swales to recreate the premining soil configuration. The operator contends that the requirement for uniform topsoil replacement is hindering the ability to achieve vegetative diversity (4).

Attention to landscape diversity needs to begin with baseline data collection for the reclamation plan and permit application. What is needed is an interdisciplinary ecological characterization of the *proposed mine area* that can be used in the design of a diverse postmining landscape, in addition to a set of numbers to be used to set performance standards. For example, baseline wildlife habitat descriptions should include measurements of physical features such as the size, distribution, and frequency of rock outcrops or the overall variety in topographic relief. This effort would be aided greatly by more exact specification of the postmining land use (see above). In addition, **research is needed to identify and describe quantitatively the physical features that are most important to the local ecology and to develop practical design criteria for use in reestablishing these features during reclamation.** Finally, better information exchange is needed among operators and regulatory authorities on the potential costs and benefits of reclamation designs that promote landscape diversity.

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14. 43 CFR 1601.0-5.
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16. 30 CFR 780.23.
17. 30 CFR 740.4.
18. 30 CFR 810.2.
19. 30 CFR 816.22
20. 30 CFR 816.41
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Chapter 9
Technological Innovation and Research

CHAPTER OVERVIEW

Since the first State reclamation laws were enacted in the early 1970s, mining companies and other organizations have undertaken a significant amount of research and developed a variety of techniques for reclaiming surface mined lands in the arid and semiarid regions of the West. The earliest research focused primarily on species adaptability and other aspects of revegetation success. Few data were available, however, and little of the research was supported by laboratory analyses or was based on broad comparative assessments until the mid-1970s. **As more mines were opened in the West, and as reclamation standards covering all types of resources were imposed, more data were collected and analyzed and a better understanding of the nature and properties of the resources being used in reclamation emerged.** This increase in the scope of mining and reclamation in the West, and in the legislative and regulatory requirements for reclamation, also led to more experimentation and innovation in reclamation techniques. Resultant data and analytical interpretation have allowed the major problems in reclamation to be defined, and have provided a scientific basis for interpreting results.

While great strides have been made in Western reclamation technology, and the prospects for the long-term success of reclamation in these regions have brightened considerably, the preceding chapters suggest that additional research still is needed in all disciplines. Although work is ongoing at Western mines that addresses most of these needs, it frequently is limited to site-specific conditions. Without comprehensive comparative analyses of the full range of Western mining environments, research at individual mines will do little to advance the science of reclamation in the West or to improve the cost-effectiveness of reclamation techniques.

To some extent, a limited amount of research always will be fostered by the regulatory programs and the mining companies' need to meet performance and design standards for reclamation. **At present, however, the most critical constraint on research is the lack of available funding.** Also, in some cases, the regulations that impose inflexible design standards can discourage innovation. Finally, the commitment to reclamation in the West that has emerged among coal companies and Federal and State regulatory authorities since 1977 must continue to grow to encompass needed research.

RECLAMATION RESEARCH PROGRAMS

Historically, research on Western surface mine reclamation has been undertaken or sponsored by Federal and State agencies, mining companies and associations, academe, suppliers of reclamation equipment, and organizations such as public interest groups. This research has been stimulated by the need to establish or meet reclamation standards or to develop more cost-effective reclamation techniques, as well as by site-specific reclamation problems. The research generally has been carried out on small dedicated research plots, although formal experimental practices under the Surface Mining Control and Reclamation Act (SMCRA; see ch. 4), and approved site-specific variances or alternative reclamation techniques under the State regulatory programs also have been considered avenues for developing innovative methods.

The earliest research programs were established and funded by government agencies in order to set performance or design standards for reclamation and to advance reclamation science sufficiently to meet those standards. Beginning in 1973, the U.S. Forest Service (USFS) administered the Surface Environment and Mining (SEAM) program, which was established to research and develop new technologies for improving the quality of mined lands. SEAM was a partnership among government agencies of all levels and research, land management, industry, and university organizations. From 1973 to 1979, SEAM sponsored more than 150 research and development projects related to the management of mineral lands. The results of the SEAM projects were disseminated through guides that focused on specific disciplines that might be affected by mining (13). In 1978, the state of the art in reclamation was deemed sufficiently well developed that the SEAM program changed its emphasis from research and development to assuring that reclamation technology is available (8). Under the auspices of the SEAM program, USFS also published a quarterly computerized listing of reclamation studies related to the Rocky Mountain West, the only bibliographic reference of its kind. The SEAM program was discontinued for budget reasons in 1979.

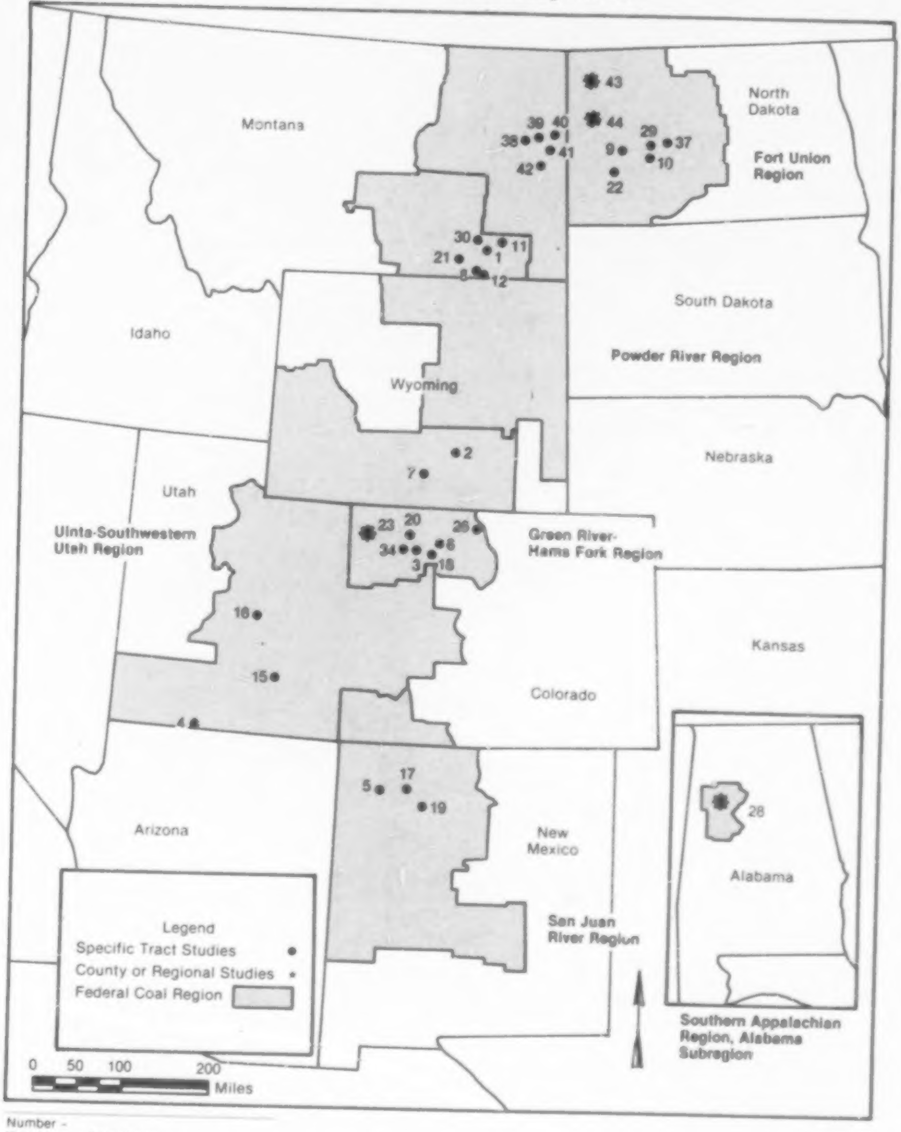
The Bureau of Land Management (BLM) funded Western coal development studies and research from 1974 to 1982 through its Energy Minerals Rehabilitation Inventory and Analysis (EMRIA) program. The EMRIA program was established to gather information about the reclamation potential on coal lease tracts and to develop lease stipulations to assure the achievement of reclamation goals for Federal coal lands. The 36 Western EMRIA reports are a multidisciplinary integration of field and literature data on geology, visual resources, overburden, hydrology, climate, soils, vegetation, and land use; figure 9-1 shows the EMRIA study areas. The studies identified site-specific problems affecting reclaimability, and recommended reclamation measures to deal with those problems (13).

The early 1980s saw the publication of the last relatively comprehensive studies of Western reclamation. In 1981, the National Research Council published reports on the effects of surface mining on soil resources, and of coal mining on groundwater resources (5,6). A cooperative study involving scientists from the U.S. Geological Survey (USGS), Soil Conservation Service (SCS), Office of Surface Mining (OSM), USFS, and BLM was published in 1983 (4). These studies examined the factors affecting reclamation in the West, evaluated the state of the art, and identified research needs and long-term uncertainties about the success of Western reclamation. It is interesting to note that **the uncertainties and research needs identified in these studies, as well as their other findings, remain valid today; little action has been taken in the interim.**

Since the late 1970s, the primary Federal responsibility for reclamation research has rested with OSM. SMCRA includes two basic vehicles for fostering research and innovation in surface mine reclamation: the State mining and mineral resources and research institutes, and the Abandoned Mine Land (AML) reclamation program. Experimental practices at active reclamation sites also may be permitted to encourage advances in mining or reclamation. SMCRA authorized appropriations to assist participating States in carrying on the work of a qualified mining and minerals resources research institute or center at a college or university with a school of mines (or equivalent). The authorization for establishing such institutes was $200,000 in fiscal year 1978, $300,000 in fiscal year 1979, and $400,000 annually for the next 5 fiscal years. The States were required to provide equal matching funds. SMCRA also established an Advisory Committee on Mining and Minerals Resources Research to determine eligibility.

SMCRA authorized research grants ($15 million authorized for fiscal year 1978, to be increased by $2 million per year for the next 6 years, to remain available until expended) to the State mining and mineral research institutes for research and demonstration projects of industrywide application, which could not otherwise be undertaken. These projects could be on any aspects of mining and minerals resources problems related to the mission of the Department of the Interior (DOI) and not otherwise being studied, and for training programs. The funding criteria for institutes and grants included a curriculum appropriate to mineral resources and engineering, and submission of annual reports on work accom-

Figure 9-1.—EMRIA Study Areas


Montana
North Dakota
Fort Union Region
South Dakota
Powder River Region
Idaho
Wyoming
Nebraska
Utah
Uinta-Southwestern Utah Region
Green River-Hams Fork Region
Kansas
Colorado
Arizona
New Mexico
San Juan River Region
Alabama
Southern Appalachian Region, Alabama Subregion
Legend
Specific Tract Studies ●
County or Regional Studies ✱
Federal Coal Region ▨
0
50
100
200
Miles
43
44
39
40
38
41
42
29
37
9
10
22
30
11
21
1
8
12
2
7
23
20
26
34
6
3
18
16
15
4
17
5
19
28

Number - Year	Title, State
1-75	Otter Creek, MT
2-75	Hanna Basin, WY
3-75	Taylor Creek, CO
4-75	Alton, UT
5-76	Bisti, NM
6-76	Foidel Creek, CO
7-76	Red Rim, WY
8-76	Bear Creek, MT
9-76	Horse Nose Butte, ND
10-77	Beulah Trench, ND
11-77	Pumpkin Creek, MT
12-77	Hanging Woman, MT
13-77	White Tail Butte, WY
14-77	Potter Mountain, WY
15-77	Henry Mountain, UT
16-77	Emery, UT
17-77	Kimbeto, NM
18-77	Fish Creek, CO
19-78	Ojo Encino, NM
20-78	Lay Creek, CO
21-78	Prairie Dog Creek, MT
22-78	Rattlesnake Butte, ND
26-79	McCallum, CO
27-79	Arkoma, OK
28-79	Overburden Analysis, AL
29-79	North Beulah Study Area, ND
30-79	Cook Mountain, MT
34-80	Collum Gulch, CO
36-80	Fattig Study Area, MT
37-80	Garrison, ND
38-80	Circle 2, MT
39-80	Thirteen Mile Creek, MT
40-80	Woodson PRLA, MT
41-80	Burns Creek, MT
42-80	S.W. Glendive, MT
43-80	Williams County, MT
44-80	McKenzie County, MT

SOURCE: U.S. Department of the Interior, *Federal Coal Management Program—Draft Environmental Impact Statement Supplement* (Washington, DC: U.S. Government Printing Office, February 1985).

plished and the status of ongoing projects. Actual expenditures for the institutes and research grants were $8,000 in fiscal year 1978, $1.8 million in fiscal year 1979, $745,000 in fiscal year 1980, and $860,000 in fiscal year 1981, when OSM funding ended and responsibility for execution of these provisions of SMCRA was transferred to the Bureau of Mines (7).

Specific applied research projects continue to be funded by OSM, either alone or in cooperation with other agencies (see table 9-1). However, OSM's research funding requests have declined from approximately $1.5 million for fiscal year 1982 to $971,000 for fiscal year 1986 (7). The breakdown for the fiscal year 1986 budget request was:

Subsidence control:	$200,000
Hydrologic studies:	180,000
Coal wastes:	220,000
Reclamation/revegetation:	150,000
Staff and administrative support:	221,000 (12)

SMCRA also required DOI to establish a center for cataloging current and projected research in all fields of mining and mineral resources. Each Federal agency doing mining and mineral resources research was required to cooperate by providing the cataloging center with information on work underway or scheduled. The center was

Table 9-1.—Reclamation Research Funded by OSM in Fiscal Years 1982 and 1983

Project	Funding[a] FY 1982	Funding[a] FY 1983	Cooperating agency
Design manual for sediment control	$ 48,000		
State of the art in alleviating soil compaction	60,000		
Improvement of overburden analytical technology	165,000		
Subsidence damage criteria	72,624		
Regional alluvial valley floor assessment	99,762	$ 97,238	
Effect of controlled overburden placement on mine soil properties	49,120		
Monitoring an excess spoil disposal site		4,992	
Analysis of performance standards for coordination with Army Corps of Engineers		4,990	
Monitoring of experimental practice for alternative sediment controls		7,000	
Analysis of gaps and duplication in regulatory process; summarize options for further development for coordinated permitting process		5,184	
Monitoring revegetation of a slurry pond site		5,000	
Monitoring a highwall retention practice		6,000	
Identification, evaluation, and demonstration of sediment control technologies		431,957	
Monitoring of mine fire extinguishing experimental practice		3,500	
Economic/environmental feasibility of lignite development in Mississippi		125,000	
Sedimentation/hydrology of surface-mined lands in Appalachian Plateau	100,000	75,000	TVA
Cumulative hydrologic impact information	275,000		USGS
Optimum moisture requirements for establishment of native species in New Mexico	120,000		USFS
Effectiveness of OSM regulation to prevent groundwater contamination	70,000		EPA
Concepts of highwall removal and AOC restoration	200,000		NAS
Aerial photography	90,000		TVA
Sampling procedures for vegetation	47,548		North Dakota
Remote sensing of AML projects	15,000		USFS
Plant materials study to identify plants suited to reclamation	92,000		USDA
Committee on ground failure hazards mitigation research		10,000	NAS
Core Support Program (Mineral and Energy Resources)	55,000	55,000	NAS
Soil survey vs. crop production as productivity measure for bond release on prime farmland		130,033	University of Illinois
National wetlands assessment workshop		10,000	FWS
Technical annotated bibliography of data sources for use by permit applicants		9,900	Indiana State University
Coordination of permitting for surface mining and dredging when mine discharges dredge materials		41,307	Smithsonian Institution
Total	$1,559,054	$1,031,076	

[a] Funding for research projects in fiscal year 1982 shown only for those projects still in progress in 1983.

SOURCE: U.S. Department of the Interior, Office of Surface Mining, *1983 Annual Report.*

to classify and maintain for public use a catalog of all mining and mineral resources research by all Federal agencies and by non-Federal agencies of government, colleges, universities, private institutions, firms, and individuals that make such information available. OTA could find no record of this center ever having been established.

Finally, SMCRA required interagency coordination of mining and mineral resources research, including: continuing review of the adequacy of Federal research programs; elimination of duplication of effort; identification of technical needs in various research categories; allocation of technical effort among agencies; review of technical manpower needs; and facilitation of interagency communication. OSM cooperates on research with a variety of agencies, including USGS, the Fish and Wildlife Service (FWS), the Tennessee Valley Authority (TVA), the National Academy of Sciences (NAS), the Environmental Protection Agency (EPA), and USFS (see table 9-1).

Research funds also are available from the Abandoned Mine Reclamation Fund, which is derived from reclamation fees levied on a per tonnage basis on all active mines. Research and demonstration projects related to the development of surface mining reclamation and water quality control program methods and techniques are fourth in order of priority for funding, after emergency and other AML projects. However, the highest priority for AML funding is for the mitigation of past mining effects. Therefore, most of the funds are spent on reclaiming individual sites rather than developing technologies that could be useful in a generic sense. Moreover, as discussed below, AML funds in the Western States tend to be allocated to non-coal sites after the abandoned coal mine emergencies have been abated and the sites have been reclaimed.

While they are not intended to be a substitute for research, SMCRA allows departures from the environmental performance standards—experimental practices—to encourage advances in mining and reclamation or to allow special postmining land uses. OSM may approve experimental practices if they potentially provide as much environmental protection as the performance standards, and are no larger or more numerous than necessary to determine the effectiveness and economic feasibility of the practice. Operators must monitor the effects of the practice to ensure the collection, analysis, and reporting of sufficient reliable data to enable the regulatory authority to evaluate its effectiveness. A staff member from OSM's Western Technical Center is assigned to be the technical coordinator for an experimental practice to ensure compliance with SMCRA and the regulations.

Since 1979, five formal experimental practices have been approved for the Rocky Mountain West. Two address alternative sediment control (see ch. 8), one (completed in 1982) involved a variance for excess spoil disposal (see ch. 3, box 3-E), one allows the disposal of mine spoil offsite to suppress an underground fire at an abandoned mine, and one involves a variance from approximate original contour in order to leave a portion of a highwall for raptor habitat (see box 9-A).

To compensate for inadequate research funding, OSM personnel would like to see more applications for experimental practices, especially in the areas of soils science (e.g., for soil moisture retention on prime farmland in North Dakota) and revegetation (8). **However, the permitting and monitoring requirements for experimental practices are difficult and expensive to meet. Few companies are willing to meet these requirements for a practice that can only be implemented on a small part of the mine-site unless the economic benefits are substantial** (e.g., the sediment control plan illustrated in ch. 8, box 8-B). Furthermore, the acceptance of an experimental practice by OSM actually is dependent on how scientifically proven the practice is in other areas or applications. As a result, experimental practices tend to provide verification of the effectiveness of a reclamation technique, rather than true advances in reclamation science or technology.

Moreover, the State programs in Montana and North Dakota do not allow the regulatory authorities to permit practices considered "experimental." In those States, most innovative reclamation methods are introduced through other program provisions (such as the Montana provision for

Box 9-A.—An Experimental Practice for Simulating Rimrock Raptor Habitat[1]

Baseline and monitoring data at this mine documented the presence of rimrock habitat (which was not disturbed by mining), as well as several active golden eagle nests on mine highwalls. As mining activities ceased in 1982 and operations shifted primarily to reclamation, there was an associated influx of golden eagles (four pair) which nested on four remaining highwalls. This highwall nesting activity posed a conflict for the mine operator: Federal and State laws prohibit leaving a highwall but also prohibit disturbing or destroying golden eagle nests.

A cooperative effort involving the mine operator, FWS, Wyoming Department of Game and Fish, and Wyoming Department of Environmental Quality (DEQ) was initiated to formulate the best techniques for resolving this conflict. Following consultation, it was decided that the best approach would be to leave one highwall and try to relocate the other two active eagle highwall nests to artificial nesting platforms (see ch. 3, box 3-P). Choice of highwall was based on the stability of the wall, the quality of nest sites provided by the wall, and the appearance and configuration of the wall in relation to surrounding terrain. The operator submitted an experimental practice request to the Wyoming DEQ and OSM to leave the one highwall, which was approved in 1983.

The associated monitoring program evaluates raptor and other wildlife use (rabbits and hares, small mammals, and songbirds) of the highwall area. Shrub seedings and direct shrub and tree transplants, along with rockpile placements, were made along the base of the wall to provide additional forage and cover for small mammals and rabbits. The effect of lost golden eagle nest sites on the eagle population in the area are not known, but suitable nest sites generally are considered to be a limiting factor on eagle populations in this region of Wyoming. Monitoring of raptor nesting activity has documented an increase in nesting pairs.

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[1] See case study mine D in reference 1.

alternative reclamation techniques), or through site-specific variances. Permit applications requesting such techniques variances still must be approved by OSM, however. OSM may require that the proposed reclamation method be permitted as an experimental practice or not allowed, as they did in the case of the alternative sediment control methods at the mine discussed in box 8-B. Many in the coal industry consider this possibility a major constraint on innovation in reclamation methods. Other companies are reluctant to propose innovative reclamation methods because if they are not approved, the company would have to expend additional time and money to revise the permit application and reclamation plan. **Although it is clear from table 9-2, below, that some research and innovation still is undertaken, greater flexibility on the part of OSM and the State regulatory authorities in judgments on proposals for the use of alternative reclamation methods at particular mine-sites, when coupled with adequate monitoring plans, could ease this constraint on innovation.**

Other special reclamation research programs sponsored by Federal agencies include:

- the U.S. Department of Agriculture, through the Agricultural Research Service;
- the USFS' annual Vegetative Rehabilitation and Equipment Workshop, sponsored by the Missoula Equipment Development Center;
- the USFS' Forest and Range Experiment Stations and regional forestry laboratories; and
- the SCS, through their State offices and Plant Materials Centers.

In addition, the Bureau of Mines, National Science Foundation, Argonne National Laboratories, USGS, FWS, NAS, and EPA have funded reclamation research. **Most of the reclamation-related research sponsored by these agencies was discontinued in the late 1970s or early 1980s as the responsibility for such research was assumed by**

Table 9-2.—Summary of Ongoing Research and Innovation at Case Study Mines[a]

Soil and overburden	Surface and groundwater	Revegetation	Wildlife
North Dakota: ND-A: Special handling of clayey soils for wetlands ND-D: Landform position and mixing of soil types to aid moisture retention in prime farmland —Effect of soil type on soil/spoil interface for optimum moisture-holding capacity	***North Dakota:*** ND-A: Restoration of wetlands	***North Dakota:*** ND-A: Transplanting native vegetation plugs for reestablishing wetlands ND-D: Restoration of woody draws —Planting, cultural and management practices for achieving grassland diversity —Irrigation, grazing, mulch, seed mixes, and topsoil handling and depth studies	***North Dakota:*** ND-A: Reconstruction of wetlands —Developing criteria for the success of wetland habitat restoration —Restoration of woody draws and native prairie on an "acre-for-acre" basis ND-D: Reconstruction of woody draws for wildlife habitat
Montana: MT-B: Retention of highwall portion as bluff extension —Use of scoria and similar soil over compacted overburden for ponderosa pine substrate —Monitoring vegetation trace metals contents to judge the success of soil reconstruction —100 percent two-lift direct-haul topsoiling MT-D: Sodium migration from sodic and clayey overburden —Topsoil erosion runoff plots	***Montana:*** MT-B: Extensive site-specific and regional groundwater database —Special handling of overburden to protect water quality MT-C: State-of-the-art PHC and CHIA analyses for proposed mine adjacent to perennial stream classified as an AVF MT-E: Management and use of very large hydrologic database —Spoil aquifer hydraulic analyses	***Montana:*** MT-A: Ponderosa pine reestablishment MT-E: Reestablishment of ponderosa pine —Coulee bottom restoration —Sodding of native grassland —Special soil handling for landscape diversity —Topsoil depth, surface manipulation, native species, legumes, phased seeding, shrub reestablishment, native hay mulch, temporary stabilizer crop, and fertilizer studies	***Montana:*** MT-D: Relocation of sage grouse strutting ground —Nest box program for American kestrels —Use of radio-telemetry and other methods to develop monitoring data to determine when impacts are due to mining versus natural variation in populations —Landscape diversity through replacement of microsites —Identification of preferred forage plants through fecal analyses to develop seed mix
Wyoming: WY-A: Detailed highwall map from stratigraphical-geochemical correlation —Intensive overburden sampling to delineate acid-forming and other deleterious strata as well as wet areas, defining highwall stability, planning shovel moves, etc. WY-B: Composite sampling of regraded spoils —Watershed erosion monitoring WY-D: Nonuniform topsoil thickness —Acidic spoil treatments —Erosion monitoring —Reclaimed geomorphology —Monitoring swell and settling WY-G: Two-lift direct-haul topsoil in desert ecosystem —Use of boron-tolerant species WY-K: Nonuniform topsoil thickness	***Wyoming:*** WY-C: Potentially acid-forming overburden WY-E: Computer modeling to predict groundwater impacts WY-G: Alternative sediment control experimental practice —State-of-the-art streamflow sampling WY-H: Restoration of essential hydrologic functions of an AVF WY-K: Formation of surface drainage channels through erosion and deposition	***Wyoming:*** WY-A: Effects of nurse crop on establishment of perennials —Effects of grazing on species composition —Mulching —Use of sagebrush "potlings" WY-C: Annual grains grown as source of soil organic matter WY-D: Methods to reduce competition between vegetation species —Planting cottonwoods in drainages WY-G: Need for irrigation in arid area WY-K: Annual rotation of experimental species WY-I: Reconstruction of a playa	***Wyoming:*** WY-J: Experimental practice to leave a highwall portion for raptor habitat

Table 9-2.—Summary of Ongoing Research and Innovation at Case Study Mines[a]—Continued

Soil and overburden	Surface and groundwater	Revegetation	Wildlife
Colorado: CO-B: Aerial and field surveys to monitor swell factors for postmining topography CO-D: Shredded mountain shrub vegetation as mulch in direct-haul topsoiling —Erosion monitoring	***Colorado:*** CO-C: Experimental practice for valley fill for excess spoil disposal CO-F: Burial of powerplant wastes in backfill	***Colorado:*** CO-A: Reclamation of pinon-juniper on massive sandstone CO-D: Live mulch for woody plant reestablishment and complete topsoil removal —Direct transplanting of tree and shrub pads using modified bucket —Omitting seeding of direct haul topsoil CO-E: Use of snowfences for water harvesting —Mulch studies CO-F: Direct transplanting of mature native shrub pads	***Colorado:*** CO-D: Detailed characterization and delineation of physical and floral features of elk calving habitat CO-F: Reestablishing premining land uses on postmining topography to facilitate best management practices
New Mexico: NM-B: Use of overburden as topsoil substitute —Use of topsoil quality evaluation system NM-D: Nonuniform topsoil thickness over spoil of varying quality —Sodium migration in a very low precipitation regime —Burial of fly ash with elevated selenium levels	***New Mexico:*** NM-C: Comprehensive erosion monitoring program NM-D: Burial of powerplant wastes in backfill	***New Mexico:*** NM-B: Use of overburden strata as topsoil substitute growth medium NM-D: Irrigation	***New Mexico:*** NM-D: Annual monitoring to provide data on wildlife use of reclaimed areas NM-E: Computer analysis of mapping and telemetry data to determine effects of mining on wildlife

[a] For the key to case study mines, see appendix A in this volume.

SOURCE: Office of Technology Assessment.

OSM. A few discipline-specific research projects relevant to particular aspects of reclamation continue to be funded at a much lower level, however.

Extensive research programs also have been conducted by university research groups, usually in cooperation with particular mines. This research covers studies related to all aspects of reclamation, including climate, soils and soil reconstruction, overburden analysis and handling, revegetation, surface and groundwater hydrology, and supplemental water (12). Western reclamation research is ongoing at: Colorado State University; Montana State University—Reclamation Research Unit and Institute for Natural Resources; North Dakota State University—Land Reclamation Research Center; Brigham Young University; University of Utah—Institute for Land Rehabilitation; and University of Wyoming. However, **because a major source of funding for these research groups is the Federal Government, the scope of their reclamation research has been curtailed significantly in recent years.**

Some State agencies also sponsor reclamation research. North Dakota's reclamation law, for example, requires the regulatory authority to provide the legislature with an annual survey of past and present reclamation research, current and future research needs, and projected estimates of funding requirements for conducting and administering reclamation research. This document is a valuable tool for anyone involved in reclamation in North Dakota (14). In Wyoming, however, the legislature has denied research monies to the regulatory authority because it is not intended to be a research agency.

In some cases, mine operators have been required to conduct applied research on specific reclamation situations through permit stipulations. Stipulations requiring monitoring cover: the extent and potential for erosion, recontoured spoil subsidence, overburden chemistry (through groundwater monitoring, leach tests, and mixing studies), soil salinity/sodicity and salt migration, the effects of irrigation water on soil salinity, and molybdenum levels in vegetation on reclaimed surfaces. Other stipulations are requiring operators to conduct research programs to develop criteria for judging the success of wetlands restoration, and to delineate suitable overburden or other alternative materials for topdressing. **As with experimental practices, permit stipulations cannot be considered a substitute for research.** Moreover, some industry representatives argue that the incidence of stipulations requiring what they consider to be "basic" research (e.g., the movement of soluble constituents at the spoil/soil interface) has increased as available government funding has declined. It is extremely difficult, however, to draw the line between applied and basic research simply because the results may be applicable to more than one reclamation situation.

Current Research and Innovation

In addition to the OSM-sponsored research projects listed in table 9-1, research and innovation is ongoing at a number of mines in the West as a result of site-specific conditions (see table 9-2), either as experimental practices or through other regulatory provisions. This research focuses on the collection of particular sets of data through baseline or monitoring studies, the use of innovative analytical techniques to evaluate reclamation situations, the development and implementation of innovative reclamation techniques, and the development of technical standards for assessing the success of innovative reclamation situations.

Historically, revegetation has been the principal subject of research at Western surface mines, primarily because the revegetation requirements have been in place the longest and because the current regulatory standards for reclamation success focus on revegetation. For the most part, this research has examined means of meeting the standards for production, cover, woody plant density, and species/lifeform diversity (see ch. 8), including means of reducing interspecies competition (see ch. 3). Other studies have emphasized particular revegetation technologies (e.g., irrigation, mulch, fertilization, seed mixes, planting methods); post-revegetation land management (e.g., grazing); or revegetation in special reclamation situations (wetlands, woody draws, coulee bottoms, playas, pinon-juniper communities, ponderosa pine woodlands).

As shown in table 9-2, **innovation in soils and overburden** focuses on special handling or treatment of acid-, alkaline-, and toxic-forming materials; on landform and other aspects of geomorphology to achieve specific reclamation objectives or postmining land uses; special soil reconstruction techniques (box 9-B; see also ch. 3, box 3-D); the use of overburden strata as topsoil supplements or substitutes; the development of analytical techniques for evaluating overburden, backfilled spoils, and topsoil quality; erosion monitoring; two-lift direct-haul topsoil handling; and nonuniform topsoil thickness.

Because of the length of time needed for groundwater restoration, much of the past hydrologic research has focused on surface water systems. Ongoing research in this area includes drainage channel design and erosion monitoring. In recent years, however, recognition of potential groundwater quality problems has grown, and current research is emphasizing the characterization, analysis, and monitoring of the interaction between backfill and aquifer restoration. Special situations under study include burial of powerplant wastes, restoration of the essential hydrologic functions of alluvial valley floors, and wetlands restoration.

Research and innovation related to wildlife emphasize the development of data and analytical techniques for describing the extent and quality of wildlife habitat and for evaluating the impacts of mining and reclamation on wildlife populations; of better and more effective means of replacing specific habitat components, such as woody vegetation, microsites, rock outcrops, and other aspects of landscape diversity; and of special reclamation techniques for the restoration or protection of important habitats, such as wetlands (box 9-B), rimrock (box 9-A; see also ch. 3, box 3-O; and ch. 8, box 8-G), woody draws (see box 3-N), and sage grouse strutting grounds (box 3-Q).

Box 9-B.—The Restoration of Wetlands[1]

At a mine in North Dakota, a multidisciplinary effort focuses on re-creating wetlands for wildlife habitat in prairie potholes. The prairie potholes were formed when blocks of ice calved off the receding glacial ice sheets and then were buried in outwash sediment. The ice melted, and depressions formed that subsequently became clogged with clayey sediments. These low permeability sediments provide the substrate conditions for the pothole wetlands.

Using a special soil reconstruction technique, the clayey soils are salvaged and stockpiled separately, and then replaced and compacted in manmade depressions on the recontoured surface designed to receive run-on water. A continuing uncertainty is the effects of disturbance of the soils on the infiltration capacity of the restored wetlands. Increased infiltration could reduce the water holding capacity of the restored wetland, while a significant decrease in the infiltration rate could affect water quality due to stagnation and evaporation.

The wildlife component of monitoring consists of general observational surveys once per week through spring and summer and twice per month during fall and winter. These surveys are performed on undisturbed habitats, on disturbed areas being mined, and then on reclaimed areas following mining. Wildlife success determinations are being developed, based on monitoring data of wildlife utilization of the reclaimed habitat. Criteria are being developed on which to base success judgments.

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[1] See case study mines: A in reference 14; C in reference 16; ND-2 in reference 15; and A in reference 1.

RESEARCH NEEDS

Each of the technical reports prepared in support of this assessment identified research needs based on the literature and on discussions with mining company, regulatory authority, and environmental group personnel, as well as academic and independent researchers (see vol. 2). These research needs are summarized in table 9-3 and discussed briefly below. In many cases, the needs cut across disciplines. For example, the definition and characterization of deleterious overburden was identified as a research need by both soil scientists and hydrologists, but problems with such overburden also would affect the quality of revegetation and, therefore, ultimately the quality of wildlife habitat.

Baseline and Monitoring Data

Table 9-3 lists four different data-related problems that must be resolved to ensure continued improvement in the prospects for the long-term success of reclamation in the West; these are discussed in detail in chapter 5. Three of these involve data that are needed but for which valid, standardized collection methods do not exist. First, reliable interpretations of the results of laboratory methods for generating chemical data about overburden are not available. Tests for selenium, nitrates, and acid-forming potential are particularly suspect (see ch. 5, box 5-C, and ch. 8). Industry already has begun research on some aspects of this problem, but additional work is needed.

Second, standardized methods for collecting data on flow and water quality in surface streams —especially ephemeral streams—also are lacking (see chs. 5 and 6). Because total suspended solids levels are a performance standard specified in SMCRA, meaningful surface water quality data are doubly important (see ch. 7). Third, standard methodologies for collecting quantitative data about the physical and floral features of wildlife habitat are not available. These are needed to provide a basis for development of design criteria for mitigation features such as rock piles and nesting boxes. Data on large mammals, raptors, and migratory birds are of regional concern, making

Table 9-3.—Research Needs for Western Surface Mine Reclamation

Soil/overburden	Hydrology	Revegetation	Wildlife
Baseline and monitoring data:			
Standardize laboratory techniques for chemical analysis of overburden for development of valid baseline data Develop a valid test for predicting the acid or base potential of postmine spoils in the West Develop quality assurance programs for chemical laboratory analyses Develop a methodology for determining sampling intensity for overburden and recontoured spoils that accounts for inherent variability in physical and chemical properties	Develop a standardized methodology for surface water quality data collection, especially for ephemeral streams Develop a digitized hydrology database to organize data on a regional level and make them readily accessible Develop a methodology for using monitoring and other data to verify and refine predictive techniques used for PHCs and CHIAs Standardize laboratory techniques to analyze overburden for chemical characteristics detrimental to water quality	Evaluate the need for collection of long-term data on erosion, productivity and cover to evaluate soil-thickness requirements and erosion control methods	Standardize definitions and quantitative measurement methodologies for physical and floral features of wildlife habitat
Predictive analytical techniques:			
Develop techniques for predicting spoils properties, particularly weathering and movement of salts into the root zone Improve erosion prediction techniques and quantitative methods for comparing erosion potential of reclaimed and undisturbed lands Develop techniques to predict long-term consolidation and settling of resaturated spoils-aquifers and the subsequent reduction in permeability in re: overburden lithology and mining technique	Develop methods for predicting site-specific post-mining spoils-water quality particularly for: a) quantifying amount of deleterious material needed before special handling imposed, and b) predicting effect of settling and consolidation of spoils in re: spoil permeability Improve models of cumulative regional groundwater quality impacts of groundwater passing through spoils of multiple mines Define conditions under which recharge by surface infiltration is desirable and develop methods for restoring this recharge capacity	Develop and validate statistical models for revegetation success that incorporate environmental baseline and reclamation monitoring data	Develop standardized quantitative habitat quality assessment methods Further development of analytical techniques similar to the FWS "HEP" model for predicting site-specific impacts of mining on wildlife Develop methods for predicting regional and cumulative impacts to wildlife Improve ability to differentiate between changes in wildlife populations caused by mining versus natural phenomena
Standards and evaluation of reclamation success:			
Evaluate plant monitoring as means of detecting undesirable trace elements in recontoured spoils and soil	Develop quantitative criteria for evaluation of surface and groundwater hydrologic restoration Develop specific criteria and methods for applying the TSS standard Refine the definition of "effective sediment control" in light of ongoing research	Improve methods for incorporating climatic and temporal variation into revegetation success standards Develop methods for adjusting performance standards based on reference areas to incorporate the range of conditions on an entire mine-site Improve methods for evaluating lifeform, seasonal, and landscape diversity Develop technical standards for shrubs and other vegetative communities, where needed	Develop design standards for the size, configuration, density of habitat enhancement and replacement, particularly physical features such as shrub patches and rock outcrops

Table 9-3.—Research Needs for Western Surface Mine Reclamation—Continued

Soil/overburden	Hydrology	Revegetation	Wildlife
Reclamation techniques:			
Examine techniques for soil resource optimization, especially over benign spoils Quantify costs and benefits of one-lift versus two-lift direct haul soil handling and their effects on revegetation Determine effectiveness of overburden mixing for various mining equipment, in terms of mitigating the effects of toxic overburden-	Determine effectiveness of various alternative sediment control methodologies Develop criteria and guidelines for disposal of powerplant wastes in backfill Develop methods of improving spoils-aquifer hydraulics and water quality through materials handling: —Using available geological materials to construct conduits through spoils areas —Through placement of granular soil layer below the rooting zone Develop technical guidelines for special-handling procedures required for various types of detrimental overburden to protect groundwater quality	Improve means of establishing woody plant density and general vegetative diversity Continue research on establishment of special plant communities (pinon-juniper, woody draws, native grasslands, etc.) Evaluate utility of various types of mulch under differing environmental conditions (e.g., climate) Evaluate use of variable topsoil and subsoil thicknesses for establishing different kinds of vegetation communities	Continue research on reconstruction of special habitats (wetlands, woody draws, pinon-juniper, etc.) Develop means of establishing landscape diversity
Basic research:			
Determine rate at which nutrients recycle and organic matter accumulates in replaced soil Evaluate need to monitor chemical and physical changes in reconstructed soils to predict long-term soil characteristics	—	Continue developing plant materials with broad genetic variability Define the specific ways in which various groups of soil microbiota affect nutrient cycling and recovery of revegetated land Examine degree of perturbation a rehabilitated ecosystem can absorb without a major shift in species composition	Establish a clearinghouse for data and research in the West Evaluate extent to which habitat availability is limiting to wildlife populations in the West

SOURCE: Office of Technology Assessment.

standardization particularly important because the data may have many users.

The fourth data research need listed in table 9-3 involves data management, which is a significant problem. Chapter 5 notes that in disciplines such as hydrology, the large amounts of raw data being collected can make its analysis very difficult and time-consuming. Yet both data and analyses are highly quantitative and regional sharing of data is extremely important. **If the enormous amounts of hydrologic and other data being collected in the West are to be useful and accessible, guidelines or criteria (e.g., a scoping system) for the baseline and monitoring data that need to be collected, and some sort of digitized data management system need to be developed. Precisely how these data management options should be implemented and what standard forms for input data should be required are themselves important topics for research.**

Analytical Techniques and Predicting Reclamation Success

As is clear from chapter 6, analytical techniques currently in use range from highly quantitative and sophisticated in hydrology, to intuitive, qualitative professional judgments in wildlife. **OTA**

found a need to improve analytical techniques used to predict the impacts of mining and to formulate reclamation plans in all of the disciplines studied. In areas such as hydrology, existing analytical tools are impressive, but so are the obstacles to and uncertainties in the analyses. Many of the highly quantitative computer models for analyzing hydrologic restoration are quite new, and data on actual hydrologic impacts will become available slowly. The validity of these models cannot be known for many years, but ideally, models should be constantly recalibrated as monitoring data are collected and model assumptions refined in light of actual events.

Often the development of analytical techniques is interrelated. Adequate methods for predicting the effects of spoil oxidation, which affects both water quality and vegetation potential, are lacking. Without valid chemical data on overburden (see above) and an ability to predict the effects of and the potential for oxidation in replaced spoils, operators will continue to have difficulty in delineating deleterious overburden and in knowing how to treat such material during mining and reclamation.

Evaluation of Reclamation Success

The development of success standards and bond release criteria are still in their infancy and a great deal of both regulatory and research work remains to be done. Because intermediate and final bond release and success determinations probably will focus on vegetation and hydrology, most of the research required will be in these areas. Two challenges in the evaluation of revegetation success are to develop standard systems that incorporate: 1) the effects of temporal and climatic variation on vegetation, and 2) a workable measure of landscape diversity. One difficulty is that diversity and ecosystem function (nutrient and energy cycling) may not be fully reestablished within the 10-year liability period.

Very little work seems to have been done to develop methods of evaluating hydrologic restoration. Where performance standards exist, there is little indication as to how they will be applied after reclamation is complete. Research is needed to develop specific quantitative criteria for evaluating virtually all aspects of hydrologic success and to determine how best to compensate for the long time required for reestablishment of aquifers and for the infrequent occurrence of peak flow events to test drainage restoration. In addition, newly developed reclamation techniques, such as the alternative sediment control measures being used at several Western mines, may require refinement of design criteria.

Reliance on vegetative and hydrologic success to determine success in soils, overburden, and wildlife is, in itself, a proposition that could bear researching. Similarly, if the physical and floral features of wildlife habitat can be quantified, as suggested above, specific design criteria for habitat and for wildlife mitigation measures (e.g., rock piles and shrub patches) can be developed and evaluated.

Reclamation Techniques

While major improvements have been made in reclamation techniques since 1977, OTA identified several areas in which new techniques need to be developed, or quantitative comparative analyses of the benefits of emerging techniques undertaken. **For soils and overburden,** these include an examination of soil resource optimization in terms of both soil quality and quantity (rather than quantity alone), and of the effectiveness of overburden mixing to dilute deleterious material for different dragline and truck-and-shovel operations. In addition, the effects of one-lift versus two-lift direct-haul topsoiling on revegetation performance standards need to be quantified in different regions, soil situations, and vegetation conditions.

Aspects of revegetation needing additional research in particular regions and site conditions include the ability to reestablish woody plant density and special plant communities (e.g., pinon-juniper woodland, native grasslands, woody draws, wetlands); the use of variable topsoil and subsoil thicknesses for establishing different kinds of vegetation communities; the effects of grazing on revegetation; and the utility of various types of mulch under different ecological and climatic conditions. **Wildlife** will benefit both from research on means to establish special communities and from improvements in methods for establishing diversity over the mine-site landscape.

For surface and groundwater hydrology, continued or additional research is needed on the effectiveness of alternative sediment control methods under various site-specific conditions, on the disposal of powerplant wastes in backfill, on methods for improving spoil-aquifer hydraulics and water quality through materials handling, and on guidelines for the special handling of various types of overburden materials that may be detrimental to groundwater quality. A major focus of the latter should be the trade-offs between extensive baseline overburden trace metal analyses combined with special handling and/or burial of deleterious overburden, versus post-reclamation monitoring and corrective action should problems arise. Related areas of inquiry are the number of inches of cover needed over acid-, alkaline- and toxic-forming overburden to protect revegetation; the methods for delineating deleterious strata; and the best place for burying deleterious materials.

In addition, many of the existing and planned reclamation areas of Western mines have longer slopes and smaller drainage densities than existed premining or that exist on adjacent undisturbed areas. Research needs to be conducted to determine whether the hydrologic balance is being protected in terms of erosional stability and infiltration/runoff relationships in such reclaimed areas.

Basic Research

As noted previously, there frequently is a fine line between basic and applied research. **When the results of site-specific research are documented carefully and disseminated publicly, they often can provide incremental advances in the science of reclamation in the West. However, research projects incorporating comparative analyses at many sites have the potential for larger improvements in reclamation technology and the understanding of reclamation science.** For example, several mines are examining the importance of landform position, slope, and aspect for moisture retention for particular vegetation types under specific ecological, physical, and climatic conditions. In order to improve the long-term prospects for the productive capability of reclaimed lands throughout the study region, this research would need to be expanded to cover the full range of different precipitation zones, vegetation, and soil types, etc., and the results disseminated and analyzed on a comparative basis.

Besides the specific research needs already discussed, OTA identified a need for more basic research in the following areas: the extent to which habitat availability limits the size and distribution of wildlife populations in the West; the rate at which nutrient and organic matter cycles reestablish in replaced topsoil; further definition of the specific ways in which various groups of soil microbiota affect nutrient cycling and recovery of revegetated land; continued development of plant materials with broad genetic variability; and the degree of perturbation a rehabilitated ecosystem can absorb without a major shift in species composition or ecosystem function (e.g., productivity).

FUNDING AND OTHER CONSTRAINTS ON RESEARCH AND INNOVATION

Constraints on research and innovation in Western surface mining may be imposed by the cost of research and limited budget resources, by regulations that impose strict design standards for reclamation or restrictions on innovation, by a lack of knowledge of past research, and from attitudes toward the role of and need for research. The most critical constraint probably is the lack of available funding for reclamation research, which frequently is very expensive. As discussed previously, research funds are limited and have declined significantly in the last few years, primarily due to Federal budget cuts. **OTA recognizes the realities of Federal budget cuts in the face of massive deficits, yet other sources of reclamation research funding need to be sought at the Federal level, in State governments, and in the private sector.**

At the Federal level, there are three potential sources of increased funding for reclamation research. First, a substantial amount of money accrues to the Federal Government through their 50 percent share of the royalties and bonus payments on Federal coal leases. These monies go into the general treasury fund, rather than being earmarked for the cost of administering the leasing program or for any other special purpose. Because these monies are derived from the extraction of Federal coal, it would be in the public interest to use some of these revenues for reclamation research to ensure that the overlying Federal lands are as productive, in the long term, as they were before coal leasing and development.

Second, SMCRA imposes a permit application fee, which may be less than but may not exceed the actual or anticipated cost of reviewing, administering, and enforcing the permit. This provision could be amended to increase the fee to create a dedicated research fund, with the amount either fixed or proportional to the size of the mining operation being permitted.

Third, as noted above, research funds are available from the Abandoned Mine Reclamation Fund. Total projected income for the AML Fund from its inception in 1978 to its scheduled termination in 1992 is estimated at $3 billion. As of September 1983, $1.32 billion had been collected. Under SMCRA, 50 percent of this money is returned to the States from which it came in the form of grants for AML programs and projects. The Federal share of $658.5 million is to be spent at the discretion of the Secretary of the Interior. As of September 1983, about $16 million had been used to carry out the inventory and perhaps $50 million had gone to administrative costs. The use of these discretionary funds is controversial, and currently is being studied by several groups, including the House Committee on Interior and Insular Affairs and the National Research Council.

These latter two options essentially shift the burden of funding research to the private sector, but the Federal Government still would be responsible for allocating the resulting funds and still would absorb a portion of the funds for administrative costs. The latter is a source of controversy because approximately 23 percent of OSM's research budget and 8 percent of the Federal AML share have gone to administration and staff support.

The Federal Government also might expand its use of permit stipulations to require coal companies to perform and monitor research projects, analyze the data, and disseminate the results. This option has fewer administrative costs to the government, since there would be no research funds to oversee, but still would require OSM Staff supervision of the research itself. **Permit stipulations, however, should not be considered a substitute for general research, because they are intended to address site-specific reclamation uncertainties.**

State government options for funding reclamation research are essentially the same as those for the Federal Government, with the addition of severance taxes and of legislative appropriations for those States whose budgets are healthier than the Federal Government's. The States collect severance taxes from coal mining, as well as their share of bonuses and royalties from leasing. Table 9-4 shows the tax rate for severance taxes, DOI estimates of potential State revenues from the Federal leasing program and from severance taxes under various coal production scenarios, and the State allocation of severance taxes.[1] The primary purpose of both severance taxes and the Federal revenue-sharing is to mitigate the social and economic impacts of coal development (e.g., population increases resulting in overloaded services such as schools, health facilities, etc.). Under the Federal Land Policy and Management Act

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[1] Note that the figures in table 9-4 do not reflect the proposed sequestering of a portion of the States' share of Federal mineral leasing revenues as a result of the Gramm-Rudman-Hollings budget cuts. Preliminary estimates by DOI were that Wyoming could lose $8.9 million in anticipated revenues in fiscal year 1986; New Mexico, $6.7 million, Colorado $1.9 million; and Montana, $900,000. An estimate was not available for North Dakota at the time of this writing. The legality of such sequestration under the Mineral Leasing Act is in dispute (11).

Table 9-4.—State[a] Severance Tax Rates and Projected Revenues

Severance tax rate[b]	Basis	1983 production[c] (tons)	Severance tax allocation[d]	Year	DOI estimate of coal (thousand dollars) royalty and severance tax revenues[b,e]		
					No new leasing	PRLA and emergency leasing	Continued leasing
Colorado:							
$00.60	per ton	10,535,211	50% severance tax trust fund 50% distributed as follows: —80% to local governments in impacted areas —15% to communities in proportion to number of residents employed in mines	1990:			
				Royalties	$13,200-$14,000	$13,200-$14,000	$13,200-$14,000
				Severance taxes	12,000-12,600	12,000-12,600	12,000-12,600
				1995:			
				Royalties	16,200-17,100	16,200-17,100	16,200-17,100
				Severance taxes	13,200-13,800	13,200-13,800	13,200-13,800
				2000:			
				Royalties	19,100-27,800	19,100-22,900	19,100-21,400
				Severance taxes	14,400-21,000	14,400-17,400	14,400-16,200
Montana:							
24.62%	% taxable value	29,477,000	50% to permanent trust fund 1.5% to alternative energy R&D 8.5% to local impact assistance 10% to education trust fund 5% to State public school equalization aid 0.5% to county land planning 1.25% to renewable resources 1.5% to parks and cultural projects trust 1% to conservation districts 0.5% to State library commission 19% to general fund	1990:			
				Royalties	14,700-15,100	14,700-15,100	14,700-15,100
				Severance taxes	113,400-116,100	113,400-116,100	113,400-116,100
				1995:			
				Royalties	24,000-25,700	24,000-25,700	24,000-25,700
				Severance taxes	118,000-126,400	118,000-126,400	118,000-126,400
				2000:			
				Royalties	25,500-41,700	25,500-43,400	25,500-37,000
				Severance taxes	125,400-205,100	125,400-213,700	125,400-182,300
New Mexico:							
$00.50	per ton	20,439,402	100% to permanent fund including principal and interest payments	1990:			
				Royalties	11,900	11,900	12,700
				Severance taxes	14,000	14,000	15,000
				1995:			
				Royalties	14,700-17,800	14,700-17,800	14,700-17,800
				Severance taxes	17,000-20,500	17,000-20,500	17,000-20,500
				2000:			
				Royalties	17,800-23,100	17,800-27,000	17,800-27,000
				Severance taxes	18,500-24,000	18,500-28,000	18,500-28,000
North Dakota:							
$00.85	per ton	18,471,000	35% for impacted localities 15% trust fund for loans to local governments 20% to coal-producing counties as follows: —30% to cities based on population —40% to county government —30% to school districts 30% general fund	1990:			
				Royalties	2,700	2,700	2,700
				Severance taxes	20,400	20,400	20,400
				1995:			
				Royalties	4,300	4,300-4,900	4,300-4,900
				Severance taxes	28,000	28,000-31,400	28,000-31,400
				2000:			
				Royalties	4,400	4,800-5,600	4,800-6,900
				Severance taxes	28,000	30,600-35,700	30,600-43,400
Wyoming:							
13.5%	% taxable value	108,321,269	Divided among: —impact fund —capital facilities account —cities and counties —water development	1990:			
				Royalties	56,300-69,900	56,300-69,100	55,300-69,100
				Severance taxes	242,600-300,300	242,600-297,200	238,300-297,200
				1995:			
				Royalties	88,200-145,200	88,200 142,900	88,200-142,900
				Severance taxes	261,300-419,700	261,300-413,500	261,300-413,500
				2000:			
				Royalties	117,200-172,300	115,500-178,300	115,500-202,000
				Severance taxes	338,330-495,500	333,600-510,200	333,600-572,300

[a] Includes all coal regions within a State.

[b] U.S. Department of the Interior, *Federal Coal Management Program—Draft Environmental Impact Statement Supplement* (Washington, DC: U.S. Government Printing Office, February 1985).

[c] From 1984 Keystone Coal Industry Manual, estimated from surface mines.

[d] ICF, Inc., "Economic Assessment of Effects of Royalties, Severance Taxes, and Diligent Development Requirements on Coal Production, Prices, and Consumer Costs," draft final report submitted to the U.S. Department of Energy, June 1982; Southern States Energy Board, *State Severance Taxes* (Atlanta, GA: December 1981).

[e] Ranges shown reflect low-high production levels.

of 1976, however, the States' share of Federal leasing revenues may be used for any public purpose. Given the total projected revenues from both sources, funds could be made available for research into mitigating the environmental impacts of coal development.

The State share of AML funds is projected to total $1.5 billion by 1992. As of September 1983, $484.7 million had been distributed to 23 States. In the Western States studied for this assessment, most of the abandoned coal emergency and high priority sites have been abated, and the States have begun using their share of the AML Fund for noncoal sites (e.g., abandoned uranium mines). While the States have broad discretion on how they use their share of these funds, there are a variety of research needs related to the mitigation of abandoned coal mines, in addition to the research needs of current surface mining reclamation. Because these funds are derived from active coal mines, the coal industry would prefer to see the funds returned to addressing their problems. Moreover, abandoned surface mine areas often are ideal sites for reclamation research.

Many States also have a "reclamation fee" as part of their permitting programs to cover administrative expenses (equivalent to the permit application fee under SMCRA). As with the Federal fee, the State reclamation fees could be increased to create a dedicated research fund.

***The coal industry* also could assume the responsibility for reclamation research through formal or informal cooperative efforts.** This is the approach taken by the electric utility industry, through the Electric Power Research Institute (EPRI; see box 9-C). Such an approach has been adopted informally by five coal companies in Illinois, who contribute a total of approximately $200,000 annually plus field plots to support research on prime farmlands performed by university agronomists (9). Similar efforts in the Western States include the Western Soil and Overburden Task Force (an industry group), which is working on improving laboratory methods and quality assurance in soil and overburden analysis to improve the possibility of developing soil and overburden resource information; the Gillette Area Groundwater Monitoring Organization, which compiles groundwater data collected by its member coal companies and publishes them in annual reports; and the Western Reclamation Group, which evaluates the technical aspects of reclamation methods and regulatory requirements.

Box 9-C.—EPRI: A Cooperative Industry Research Organization

EPRI is a national organization that conducts research and development (R&D) for the electric utility industry. EPRI is the successor to the Electric Research Council (ERC), which was organized in 1965 to encourage all sections of the industry to join in cooperative sponsorship of electric energy research. In 1969, ERC set up a Task Force to draw up a blueprint for utility industry R&D through the year 2000. Concurrently, ERC worked out the details for an industrywide organization to provide direction and support for R&D. The result was EPRI, which incorporated both ERC and the Edison Electric Institute's R&D programs.

EPRI is supported by voluntary contributions from its members, which include investor-, public-, and cooperatively owned electric utilities and government agencies involved in power production. Guidelines were established under which member companies were asked to contribute at a level proportional to the number of kilowatt-hours sold (0.1 mill/kWh in 1974). R&D is not actually conducted at EPRI offices, but at universities, manufacturing plants, utility sites, or wherever else needed skills and facilities exist. Advisors on EPRI's R&D agenda include: the Board of Directors of 15 executives from member utilities; a Research Advisory Committee of 24 senior research directors and vice presidents of utilities that works with EPRI's senior staff on technical program agendas; and a 25-member Advisory Council drawn from the research committee of the National Association of Regulatory Utility Commissioners and a cross-section of the public (2).

Such a cooperative structure for industry-funded research would be more equitable than the current situation in which a few companies shoulder the burden of research through experimental practices and permit stipulations. As with EPRI, advisory committees comprised of industry representatives, supplemented with academic, regulatory, and interest group personnel, could evaluate the need for particular types of research in different ecosystems, with the research results disseminated to all members as well as to regulatory authorities, academic researchers, and other interested parties. Because the coal industry, unlike the electric utility industry, is competitive, the antitrust implications of a formal cooperative research organization are unclear.

A second set of constraints on research and innovation in surface mining reclamation results from legislation or regulations that impose rigid design standards or place strict limitations on innovation. The design standards in SMCRA and the regulatory programs cover sedimentation control technologies, topsoil thickness and suitability, and approximate original contour and highwall reduction (see chs. 4 and 7). As discussed in chapter 8, research to date suggests that there may be some situations in which these standards either may unnecessarily increase the cost of reclamation or may even undermine efforts to improve the quality and capability of the land. On the other hand, design standards for these aspects of reclamation generally are easier to enforce than performance standards, especially in disciplines where there are few if any monitoring requirements or criteria for evaluating reclamation success. The main problem is how to encourage innovation while maintaining regulatory control (see box 9-D).

While limited research on alternatives to these design standards is underway in the West (see notes on mines MT-B, ND-D, NM-D, WY-G, WY-J, WY-K in table 9-2), **it must either be carried out under the stringent requirements for a formal experimental practice, or the permit applicant must obtain a variance. The difficulty and cost of either avenue poses a significant obstacle to the extension of this research to other mining situations.**

Box 9-D.—Regulatory Control of Innovation[1]

A situation at a mine in northwestern Colorado illustrates a conflict where both the mining company and the regulatory authority are restricted by regulations written at a time when improvements in revegetation technology were not foreseen.

At issue is a request by the mine to have the seeding requirement waived on areas receiving direct haul topsoil. The company asserted that seeding was unnecessary due to abundant volunteer growth from seeds and vegetative parts within the relocated soil, which had been treated before removal with a tractor-mounted shredder, producing "live" mulch from existing vegetation. The regulatory authority, although cognizant of the effectiveness of the treatment, was unable to grant the waiver because to do so would have conflicted with the Federal requirement for seeding or planting. The company responded that the presence of viable seeds and potentially regenerative roots in the soil constitutes seeding and planting and leads to the establishment of plants better adapted to the site than are available in commercial seed mixes. The regulatory authority also was reluctant to set a precedent that could lead to similar requests in areas that were not as suitable for this procedure, especially since the waiver would occur without compliance with the State requirements for prior regulatory approval of field trial design.

At present, the two parties have agreed to handle the matter as a minor revision to the permit, rather than a waiver or technical revision as previously sought. This will allow formal approval of the proposed practice as a field trial and continued monitoring of its effectiveness at this mine.

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[1] See case study mine CO-1 in reference 15.

One option is to incorporate alternative sets of design standards in State guidelines, with approval of their use at a particular mine depending on site-specific environmental and operational conditions. Guidelines are more flexible than regulations, but some State regulatory authorities are reluctant to use them (they are not allowed under the North Dakota legislation). **A second option for encouraging innovation while maintaining regulatory control would be to keep design standards but make maximum use of the phrase "unless otherwise approved by the regulatory authority" or to liberalize the requirements for a variance or experimental practice.** Design standards could be enforced strictly when necessary, and innovation encouraged when possible.

In either case, the regulatory authority should ensure that shifts from design to performance standards, or variances from design standards are backed up with strict criteria for evaluating the success of the reclamation, and with requirements for monitoring and analysis of the resulting data. Ultimately, however, judgments about a proposed practice's success must depend heavily on the technical expertise within the regulatory authority.

A third set of constraints on research and innovation results from a lack of data or of knowledge about past research. In areas where reclamation problems are just beginning to be recognized, baseline or monitoring data may not be available, or analytical techniques may not have been developed. For example, the potential for, effects of, and best means of handling acid production from spoils are not understood, yet only in Wyoming are studies of the acid-base potential routinely required in baseline overburden studies, and uncertainties about the results of such studies remain unresolved (see ch. 8). Similarly, there has been very little research on the optimum depth of soil as a function of soil quality. Present baseline analyses do not evaluate characteristics such as the organic matter in, or moisture-holding capacity of, either the reclaimed soils or recontoured spoil, and soil suitability generally is based on chemical and physical parameters. Therefore, regulatory programs that require the salvage of all suitable soil may not be optimizing soil depth.

Furthermore, **there are few vehicles for dissemination of reclamation research results.** In some cases, companies may prefer to keep such information confidential for competitive reasons. But even when competition is not a concern, reclamation specialists at mines, regulatory agencies, and other research groups must rely on word-of-mouth and infrequent conferences or symposia to learn about research and innovation at Western surface mines. **Regular publication of research/innovation newsletters by regulatory authorities and regular compilation of a bibliography on reclamation research (similar to the publications previously issued by the USFS' SEAM program) would greatly assist information dissemination.**

Finally, **attitudes toward the role of and need for research on Western surface mine reclamation can pose a significant constraint on research and innovation.** Reclamation research, including documenting the effectiveness of innovative practices, can be expensive. As a result, each of the parties—coal companies, and Federal and State regulatory authorities—tends to believe that the economic responsibility for such research lies with one of the other parties. Implementing the options for increased research funding discussed previously would alleviate this problem. But the commitment to meeting the legislative standards for reclamation that has emerged among all of these parties since 1977 must continue to evolve to ensure that attitudes toward research also change.

A second aspect of this problem is the allocation of limited Federal research monies among Eastern, Midwestern, and Western reclamation problems. Western (and Midwestern) regulatory authority personnel and coal operators argue that a disproportionate amount of such funds is dedicated to Eastern mining situations and problems. To resolve this dispute, **OSM should undertake a study, with participation by operators and regulatory authorities from all parts of the country, to ascertain regional research needs and determine the priorities and relative costs of meeting those needs.**

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Appendixes

Appendix A

Key to Case Study Mines

State/Mine	Soils[a]	Hydrology[b]	Revegetation[c]	Wildlife[d]
North Dakota:				
ND—A	A	C (3.3)	ND—2	A
ND—B	—	D (3.4)	—	—
ND—C	—	B (3.2)	—	—
ND—D	B	A (3.1)	ND—1	B
Montana:				
MT—A	—	—	MT—2	—
MT—B	C	F (3.6)	—	—
MT—C	—	E (3.5)	—	—
MT—D	D	H (3.8)	—	C
MT—E	—	G (3.7)	MT—1	—
Wyoming:				
WY—A	E	—	WY—1	—
WY—B	F	—	—	—
WY—C	—	M (3.13)	WY—5	—
WY—D	G	—	WY—2	—
WY—E	—	L (3.12)	—	—
WY—F	—	N (3.14)	—	—
WY—G	I	I (3.9)	WY—3	—
WY—H	—	J (3.10)	—	—
WY—I	—	—	WY—6	—
WY—J	—	—	—	D
WY—K	H	K (3.11)	WY—4	—
Colorado:				
CO—A	—	—	CO—4	—
CO—B	K	—	—	—
CO—C	—	Q (3.17)	—	—
CO—D	J	O (3.15)	CO—1	E
CO—E	—	—	CO—2	—
CO—F	—	P (3.16)	CO—5	F
CO—G	—	—	CO—3	—
New Mexico:				
NM—A	—	T (3.20)	—	—
NM—B	M	—	NM—1	—
NM—C	—	S (3.19)	—	—
NM—D	L	R (3.18)	NM—2	H
NM—E	—	—	NM—3	G

[a] James P. Walsh & Associates, "Soil and Overburden Management in Western Surface Coal Mine Reclamation," contractor report to OTA, August, 1985).

[b] Western Water Consultants, "Hydrologic Evaluation and Reclamation Technologies for Western Surface Coal Mining," contractor report to OTA, August 1985.

[c] Western Resource Development Corp. and J. Bunin, "Revegetation Technology and Issues at Western Surface Coal Mines," contractor report to OTA, September 1985.

[d] Cedar Creek Associates, "Wildlife Technologies for Western Surface Coal Mining," contractor report to OTA, August 1985.

Appendix B

List of Acronyms and Abbreviations

ABP	—acid-base potential
ACEC	—Area of Critical Environmental Concern
AML	—Abandoned Mine Land Program
AOC	—approximate original contour
AVF	—alluvial valley floor
B	—boron
BLM	—Bureau of Land Management
Btu	—British thermal unit
CDOW	—Colorado Department of Wildlife
CFR	—Code of Federal Regulations
CHIA	—cumulative hydrologic impact assessment
cm/yr	—centimeters per year
CO	—Colorado
DEQ	—Wyoming Department of Environmental Quality
DOI	—U.S. Department of the Interior
DSL	—Montana Department of State Lands
EA	—environmental assessment
EC	—electrical conductivity
ECO	—engineered cast overburden
EHF	—essential hydrologic functions
EIS	—Environmental Impact Statement
EMRIA	—Energy Minerals Rehabilitation Inventory and Analysis
EPA	—U.S. Environmental Protection Agency
EPRI	—Electric Power Research Institute
ESP	—exchangeable sodium percent
FCLAA	—Federal Coal Leasing Amendments Act of 1976
FDM	—finite-difference model
FEM	—finite-element model
FLPMA	—Federal Land Policy and Management Act of 1976
FONSI	—finding of no significant impact
ft	—foot
FWS	—U.S. Fish and Wildlife Service
FY	—fiscal year
GAGMO	—Gillette Area Groundwater Monitoring Organization
gpd	—gallons per day
gpm	—gallons per minute
HEP	—Habitat Evaluation Procedures program
KRCRA	—Known Recoverable Coal Resource Area
lb	—pound
m	—meter
MBMG	—Montana Bureau of Mines and Geology
mg/l	—milligrams per liter
ml/l	—milliliters per liter
MLRD	—Colorado Mined Land Reclamation Division
MMD	—New Mexico Mining and Minerals Division
MMS	—Minerals Management Service
Mo	—molybdenum
MT	—Montana
N	—nitrogen
NAAQS	—National Ambient Air Quality Standards
NAS	—National Academy of Sciences
NAWDEX	—National Water-Data Exchange
ND	—North Dakota
NEPA	—National Environmental Policy Act of 1969
NGWIC	—National Ground Water Information Center
NM	—New Mexico
NOAA	—National Oceanic and Atmospheric Administration (DOI)
NOV	—Notice of Violation
NPDES	—National Pollutant Discharge Elimination System
NRC	—National Research Council
NSPS	—New Source Performance Standard
OSM	—Office of Surface Mining
OTA	—Office of Technology Assessment
PHC	—probable hydrologic consequences
ppm	—parts per million
PRP	—Federal permanent regulatory program
PSC	—North Dakota Public Service Commission
RA	—regulatory authority
RCT	—Regional Coal Team
SAR	—sodium adsorption ratio
Sat%	—moisture content saturation
SCS	—Soil Conservation Service
Se	—selenium
SEAM	—Surface Environment and Mining Program
SMCRA	—Surface Mining Control and Reclamation Act of 1977
SSA	—Site-specific Analysis
TDS	—total dissolved solids
tpd	—tons per day

tpy	—tons per year
TSS	—total suspended solids
TVA	—Tennessee Valley Authority
URA	—Unit Resource Analysis
USC	—United States Code
USDA	—U.S. Department of Agriculture
USFS	—U.S. Forest Service
USGS	—U.S. Geological Survey
USLE	—Universal Soil Loss Equation
WATSTORE	—National Water-Data Storage and Retrieval System
WWRC	—Wyoming Water Research Center
WY	—Wyoming

Appendix C
Glossary

Alluvium: Sand, silt, or clay that has been deposited on land by streams.

Aquifer: A body of earth strata capable of transmitting water through its pores at a rate sufficient for water supply purposes.

Arroyo: A water-carved gully or channel in arid areas.

Aspect: The direction a slope faces; affects temperature, moisture (e.g., snow accumulation and retention), and wind exposure, and hence can dramatically influence vegetation.

Available water: The portion of water in a soil that can be absorbed by plant roots. The amount of water released by the soil when the equilibrium soil water matrix potential is decreased from field capacity to −15 bar.

Base flow: That portion of the stream discharge which is derived from groundwater outflow or other sources outside the net rainfall which created the surface runoff.

Bench: A thickness of overburden handled as a layer.

Browse: Palatable shrubs.

Calcareous: Soil containing sufficient free calcium carbonate or calcium: magnesium carbonate to effervesce visibly when treated with cold 0.1N hydrochloric acid.

Carrying capacity: The amount of livestock or wildlife use that an area is able to support; relates to forage production, water, shelter, etc.

Climax: The kind of community capable of perpetuation under the prevailing climatic and substrate conditions, assuming long-term absence of disturbance. See *Succession*.

Coulee: A drainageway that is steep-sided and normally is dry by late summer.

Cover (absolute): The percentage of the ground covered by above-ground portions of plants; may be expressed by species, lifeform, or totaled; values for litter, rock, and soil may be similarly reported.

Cover (relative): The proportion of the total absolute cover contributed by each plant species.

Crest-gage station (or Crest-stage gage station): A simple measuring device used to obtain a record of flood crests at sites where recording gages are not present.

Cumulative hydrologic impact assessment (CHIA): A determination of the probable additive impacts to surface and groundwaters associated with all existing and anticipated mining in an area.

Dancing ground: Small clearings and/or hilltops used by sharptail grouse for their breeding activities; also referred to more generically as a *lek*.

Dendritic: Branching or treelike forms.

Dip: The angle that a structure surface (i.e., bedding), makes with the horizontal measured perpendicular to the strike.

Discharge: In its simplest concept, discharge means outflow of water; therefore, the use of this term is not restricted as to course or location and it can be applied to describe the flow of water from a pipe, aquifer or from a drainage basin. Flow rates in canals or streams are often referred to as discharge rates. It is also correct to speak of the discharge of a canal or stream into a lake, stream, or ocean.

Dissected plateau: A flat topographic bench exhibiting one or more large erosion gullies or arroyos.

Diversity: The variation of heterogeneity of species or lifeforms within one plant community, which may incorporate "richness" (species or lifeform number) and "evenness" (comparative species or lifeform abundance).

Drainage basin: A part of the surface of the earth that is occupied by a drainage system, which consists of a surface stream or a body of impounded surface water together with all tributary surface streams and bodies of impounded surface water.

Edge effect: The result of the overlap (ecotone) of two adjoining plant communities on the quantity and diversity of wildlife in the immediate vicinity.

Ephemeral stream: A stream that flows only in direct response to precipitation, and thus discontinues its flow during the dry seasons. Its channel is above the level of the water table.

Erosion: The group of processes whereby earth or rock material is loosened or dissolved and removed from any part of the earth's surface.

Escape cover: Floral cover thick enough to provide a visual or physical protective barrier for animals.

Flood plain: Nearly level land, consisting of stream sediments, that borders a stream and is subject to flooding unless protected artificially.

Forb: A nongrassy (i.e, broadleaf) herbaceous plant; includes many species commonly referred to as wildflowers or weeds.

Gaging station: A particular site on a stream, canal, lake, or reservoir where systematic observations of gage height or discharge are obtained.

Game animals: A group of animals legally protected under the various game laws of the States, usually taken for human consumption as regulated by hunting laws (e.g., deer, rabbits, ducks, etc.).

Geomorphology: That branch of both physiography and geology which deals with the form of the earth, the general configuration of its surface, and the changes that take place in the evolution of land forms.

Grassland: An area of vegetation dominated by grasses, with other types of plants (e.g., shrubs) present in low numbers.

Habitat affinity: The expressed preference shown by a particular species for certain associations of physical and biotic features of the environment.

Herbaceous: A type of plant with no woody parts (e.g., grasses and forbs).

Highwall: The unexcavated face of exposed overburden and bedrock in a surface mine.

Hogback: A sharp-crested ridge formed by the outcropping edges of steeply inclined resistant rocks.

Hydraulic conductivity: Ratio of flow velocity to driving force for viscous flow under saturated conditions of groundwater in a porous medium.

Hydrograph: A graph showing, for a given point on a stream or conduit, the stage, velocity of flow, available power, or other function of the discharge with respect to time.

Hydrostratigraphy: The study of the relationships between the occurrence and characteristics of groundwaters and the geologic features of the rock units forming aquifers.

Indicator species: A particular kind of animal which, by its mere presence in a given area, indicates the existence of a known associated habitat or habitat feature, lack of disturbance, or other condition; for example, aquatic invertebrates such as mayfly or stonefly larvae indicate unpolluted stream waters.

Infiltration rate: The rate at which water enters the soil; it has the dimensions of velocity.

Intermittent stream: One which flows only at certain times of the year when it receives water from springs or from some surface sources such as melting snow in mountainous areas.

Lek: An assembly area where birds, especially members of the grouse family, gather for display, courtship, and breeding activity.

Lenticular: Stratigraphic units that are discontinuous horizontally.

Lifeform: Structural categories of plant types, commonly set forth as annual grass, perennial grass, annual forb, perennial forb, subshrub, shrub, tree, etc.

Line intercept: A method of estimating plant cover by measurement of the interception of vertical projection of plant canopies or parts along a horizontal line.

Lithology: The physical character of a rock.

Litter: Undecomposed dead plant parts accumulated at the ground surface.

Morphological: Pertaining to shape or form.

Mycorrhiza: Literally "fungus root." The association, usually symbiotic, of specific fungi with the roots of higher plants.

Native rangeland: Grazingland dominated by naturally occurring plant species; generally requires low levels of active management other than controlling the intensity, season, and duration of use by livestock.

Nesting box: A structure built by man for the artificial replacement of cavity nesting habitat. Other nesting structures, such as platforms, are common management tools for aiding avifauna dependent on specific landscape features for nesting success.

Nurse crop: A short-lived plant cover (e.g., annual grains) sometimes planted in the initial year of revegetation to protect the seedlings of perennial species from desiccation by sun or wind. A related practice is mowing the annual plant cover in the fall prior to the perennials' planting, thereby producing a "stubble mulch."

Partial-record station: Particular site where limited streamflow or water-quality data, or both, are collected systematically during a period of years for use in hydrologic analysis.

Partings: Thin shale layers within the coal seam.

Pastureland: Grazing dominated by introduced ("tame") grasses and forbs (e.g., alfalfa, clover) that is highly productive but requires moderate to high levels of active management such as fertilizers, periodic reseeding, and weed control. Often rotated in use with hayland or allowed to periodically lie fallow.

Peak-discharge: Peak flow rate. The term is normally used in regard to the peak flow rate in a stream during a flood event.

Pedestalling: The process by which small pedestals form under stones through erosion.

Pedologic: Pertaining to soils.

Pedon: A three-dimensional body of soil with lateral dimensions large enough to permit the study of horizon shapes and relations. Its area ranges from 1 to 10 square meters.

Pellet group: The fecal material left by ungulates (deer family).

Perennial stream: A stream that flows at all times.

Piezometer: An instrument for measuring pressure head in a conduit, tank, soil, etc. It usually consists of a small pipe or tube tapped into the side of the container, the inside end being flush with, and normal to, the water face of the container, connected with a manometer pressure gage, mercury or water column, or other device for indicating pressure head. Certain wells can be used as piezometers to measure pressure heads in aquifers.

Playa: A shallow depression with no external drainage that dries up for part of the year. The occasional inundation and tendency for development of heavy clay soils results in distinctive vegetation tolerant of such conditions.

Point intercept: A method of estimating cover by the interception of above-ground plant parts (and litter, rock, or soil) by a vertically projected point, as defined by a sharp pin or by cross-hairs in a viewing device.

Point source: A single source of contamination to surface or groundwater. Point source also may refer to a highly localized area of surface or groundwater contamination.

Population estimates: Actual estimates of an animal's population numbers based on a sample of that population.

Population size indices: An index which identifies the relative size of a particular species' population without statistically sampling the actual population.

Potentiometric surface: Surface to which water in an aquifer would rise by hydrostatic pressure.

Prairie pothole: A regional term for the small wetlands commonly occurring in the glaciated portions of the Northern Great Plains.

Probable hydrologic consequences (PHC): The projected effects of a mining operation on the quality and quantity of surface and groundwater; depth to groundwater; surface and groundwater flow, timing and pattern; stream channel conditions; and aquatic habitat.

Production: The weight (usually oven dry) of annual growth of above-ground plant parts (i.e., "standing crop"); usually expressed as weight ("biomass") per unit land area.

Propagule: Plant tissue which, if separated from the plant, will give rise to a new individual (seeds, certain types of buds, etc.).

Quadrat: A plot of variable size, used to measure or estimate a vegetation parameter such as production or cover.

Range site: A vegetation unit traditionally defined as an area where the physical environment (topographic, soils, and climate) is sufficiently uniform to produce the same potential or climax vegetation.

Raptor: A bird of prey.

Refuge effect: The tendency for animals to congregate on coal mine properties due to the "no trespassing" and "no firearms" policies of many mines, which removes hunting and harassment pressures from big game.

Regolith: Loose, incoherent weathered rock below the soil.

Rider seams: Thin coal seams above the main coal.

Rimrock: Erosionally resistant rock of a plateau that outcrops to form a vertical face.

Riparian areas: Areas exhibiting plants associated with frequent surface or persistent subsurface water, such as along the banks of a stream.

Runoff: That part of the precipitation that appears in uncontrolled surface streams, drains, or sewers. It is the same as streamflow unaffected by artificial diversions, imports, storage, or other works of man in or on the stream channels.

Runoff hydrograph: A graph showing, for a particular watershed, a time record of stream surface elevation or stream discharge at a given cross-section of the stream for a rainfall event.

Saline seeps: Spring water soluble salts accumulate at the ground surface.

Scat: Wildlife fecal matter.

Scoria: Rock material affected by the burning of underlying coal, also known as clinker.

Seasonality: In plant ecology, refers to the time of the growing season when maximum growth occurs; especially used to differentiate between cool-season grasses (peak growth in spring and fall) and warm-season grasses (peak growth in summer).

Sedimentation pond: A primary sediment-control structure designed, constructed, and maintained to slow down water runoff to allow sediment to settle out; includes barriers, dams, or excavated depressions.

Shelterbelt: A grouping of trees and shrubs usually planted perpendicular to prevailing winds to serve as a windbreak for buildings or to reduce soil erosion in croplands.

Shrub: A perennial woody plant, smaller than a tree and typically with more than one main stem, whose over-wintering buds are borne on twigs above the ground.

Shrub steppe: A broad floral community of the Western Great Plains and foothills of the Rocky Mountains typified by a shrub (usually sagebrush) overstory.

Sodium adsorption ratio (SAR): A relation between soluble sodium and soluble divalent cations which can be used to predict the exchangeable-sodium percentage of soil equilibrated with a given solution. It is defined as follows:

$$\text{SAR} = \frac{\text{sodium, mmoles/liter}}{(\text{calcium} = \text{magnesium})^{1/2}(\text{mmoles/liter})^{1/2}}.$$

Soil: (1) The unconsolidated mineral material on the immediate surface of the earth that serves as a natural medium for the growth of land plants. (2) The unconsolidated mineral matter on the earth's surface that has been subjected to and influenced by genetic and environmental factors of: parent material, climate (e.g., moisture and temperature), macro- and micro-organisms, and topography, all acting over a period of time and producing a product—soil—that differs from the material from which it is derived in many physical, chemical, biological, and morphological properties and characteristics.

Soil classification: The systematic arrangement of soils into groups or categories on the basis of their characteristics. The USDA soil classification system (soil taxonomy) was adopted for use in publications by the National Cooperative Soil Survey.

Soil horizon: A layer of soil, approximately parallel to the surface, that has distinct characteristics produced by soil-forming processes.

Soil phase: A subdivision of a soil type or other unit of classification having characteristics that affect the use and management of the soil but which do not vary sufficiently to differentiate it as a separate type. A variation in a property or characteristic such as degree of slope, degree of erosion, content of stones, etc.

Soil profile: A vertical section of the soil through all its horizons and extending into the parent material.

Soil series: The basic unit of soil classification, being a subdivision of a family and consisting of soils which are essentially alike in all major profile characteristics except the texture of the A horizon.

Soil structure: The combination or arrangement of primary soil particles into secondary particles, units, or peds.

Species diversity values: A mathematically calculated index value that indicates the relative diversity of animals in a given habitat or area.

State sensitive species (or sensitive species): Nongame wildlife species which are rare or have very limited habitat in a particular State and are therefore afforded some degree of protection.

Station: Ground position at which a geophysical instrument is set up for observation in the field.

Storage coefficient: (1) For surface waters, a coefficient that expresses the relation of storage capacity in a reservoir, to the mean annual flow of a stream above the dam forming the reservoir. (2) For groundwaters, the cubic feet of water discharged from each vertical column 1 ft. square as the water level drops 1 ft.

Stratigraphic correlations: The process by which stratigraphic units in two or more separate areas are shown to be laterally similar in character or mutually correspondent in stratigraphic position.

Stratigraphy: The arrangement of strata.

Streamflow: The discharge that occurs in a natural channel. "Streamflow" is more general than runoff, as streamflow may be applied to discharge whether or not it is affected by diversion or regulation.

Strutting ground: Small clearings and/or hilltops used by sage grouse for their breeding activities; also referred to more generically as a *lek*.

Subshrub: A perennial plant which is woody at its base and is either of small stature or dies back nearly to ground level (i.e., intermediate between a shrub and a forb).

Subsoil: The soil horizons underlying topsoil, typically the B and C horizons.

Succession: The natural progression of plant communities following partial or complete disturbance; theoretically culminates in the "climax" community.

Surface soil: The uppermost part of the soil, ordinarily moved in tillage or its equivalent in uncultivated soils and ranging in depth from 3 to 4 inches to 8 or 10. Frequently designated as the "plow layer," the "Ap layer," or the "Ap horizon."

Suspended sediment: The very fine soil particles which remain in suspension in water for a very considerable period of time without contact with the bottom.

Swell factor: The amount of expansion on excavation expressed as a multiple of one or a percent.

Talus slope: A slope covered with loose rock.

Telemetry: The wildlife management technique involving the attachment of a radio-transmitting collar to animals thereby facilitating their relocation with radio receivers.

Threatened and endangered species: Any species of animal or plant that falls under the protection of the Endangered Species Act and is listed in the Federal Register. Some States may also have listings that expand the Federal list.

Till: Unstratified glacial drift deposited directly by the ice and consisting of clay, sand, gravel, and boulders intermingled in any proportion.

Tilth: The physical condition of soil as related to its ease of tillage, fitness as a seedbed, and impedance to seedling emergence and root penetration.

Time of concentration: The time required for water to flow from the farthest point on the watershed to the gaging station or other point of interest.

Topsoil: (1) The surface horizons of a soil, typically A and E Horizons. (2) The materials used as a top dressing for soil reconstruction over regraded spoil.

Total dissolved solids (TDS): The total quantity of chemical constituents or elements in solution in ground or surface waters.

Total suspended solids (TSS): The velocity-weighted concentration of suspended sediment expressed as milligrams of dry sediment per liter of water-sediment mixture.

Transect: A line or narrow belt along which ecologic data are collected, either continuously (e.g., total counts of trees) or periodically (e.g., periodic location of cover or production samples).

Transmissivity: The rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of an aquifer under a unit hydraulic gradient. Commonly expressed in gallons per day per foot (gpd/ft).

Walrus scat: Popcorn.

Watershed: All lands enclosed by a continuous hydrologic drainage divide and lying upslope from a specified point on a stream.

Wetlands: Land containing significant soil moisture and/or free-standing water; usually accompanied by a diverse community of riparian and emergent vegetation.

Woody draws: Broadleaf tree and shrub communities occurring along perennial or intermittent drainages, or bottoms, of more mesic draws and coulees; usually in reference to the Northern Great Plains wooded draws.

Woody plant: Any perennial plant that produces wood fibers in its above-ground parts and whose over-wintering buds are borne above the ground; includes trees, shrubs, and subshrubs.

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